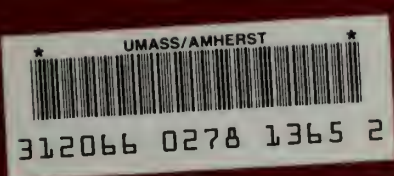


MASS

UM14.2

V42



Environmental Engineering

Technical Report

Variation of Heavy Metals
Concentrations in Municipal
Sludge and Sludge Compost
November, 1989

George D. Bacon
Research Assistant

Michael S. Switzenbaum
Associate Professor of Civil Engineering

Department of Civil Engineering
University of Massachusetts at Amherst



GOVERNMENT DOCUMENTS
COLLECTION

NOV 30 1990

University of Massachusetts
Depository Copy

Technical Report

Variation of Heavy Metals
Concentrations in Municipal
Sludge and Sludge Compost
November, 1989

George D. Bacon
Research Assistant

Michael S. Switzenbaum
Associate Professor of Civil Engineering

November 1989
Env. Eng. Report No. 108-89-4

Technical Report

Variation of Heavy Metals Concentrations
in Municipal Sludge and Sludge Compost
R&D#87-01-02

by

George D. Bacon
Research Assistant

and

Michael S. Switzenbaum
Associate Professor of Civil Engineering

Environmental Engineering Program
Department of Civil Engineering
University of Massachusetts
Amherst, MA 01003

Submitted to the

Commonwealth of Massachusetts
Department of Environmental Protection
Division of Water Pollution Control
Daniel S. Greenbaum, Commissioner
William P. Gaughan, Acting Director



ACKNOWLEDGEMENTS

The authors wish to thank Professors James K. Edzwald and William R. Knocke, Daniel Wagner and the rest of the Environmental Engineering Program for their help and guidance. Other valuable assistance was provided by the following people: George Heisler of the Hoosac Water Quality District, Dr. Michael De Cheke of the Microanalysis Laboratory, Dr. Michael Sutherland of the Statistical Consulting Center, and Eva Goldwater of the VCC Data Analysis Group. We are also grateful to the Massachusetts Division of the Water Pollution Control for funding this research.



ABSTRACT

The purpose of this research was to examine the variation of heavy metals concentrations in municipal sludge and sludge compost. The variation was examined within a wastewater treatment plant to determine the fate of metals during sludge treatment and disposal.

The research was completed in two parts. First, a detailed literature review was completed to examine the sources of heavy metals in wastewater and their fate during treatment. Next, a field study was conducted at an existing wastewater treatment plant practicing sludge composting in Williamstown, Massachusetts.

A sampling and analysis program was devised to measure the concentrations of cadmium, chromium, copper, nickel, lead and zinc in the solids stream of the plant. Concentrations of these metals were measured in the sludge before and after composting, and in compost stored on site.

The results were that the concentrations of cadmium, chromium, lead and zinc were typically higher in the compost than the parent sludge. Concentrations of copper and nickel were typically lower in the compost than in the sludge. Statistical analysis of the data indicated that these differences were significant.

Cadmium, copper, nickel and zinc were detected in the filtrate from the sludge dewatering and in the leachate from the



Digitized by the Internet Archive
in 2015

<https://archive.org/details/variationofheavy00baco>

compost piles. The source of the cadmium and zinc were not determined. The copper and zinc were apparently displaced from the sludge during lime conditioning.

Variability of the metals concentrations during the study period in the sludge, batch compost and stored compost were different for different metals. The difference between metals concentrations in batch compost and stored compost samples varied depending on the metal studied and the difference in age between the two sample types.

TABLE OF CONTENTS

Acknowledgements.....	iv
Abstract.....	v
List of Tables.....	ix
List of Figures.....	xi
 I. INTRODUCTION.....	 1
II. LITERATURE REVIEW.....	5
2.1 METALS IN MUNICIPAL WASTEWATER	
TREATMENT PLANTS.....	5
2.1.1 Typical Levels and Variability:	
Wastewater and Sludges.....	5
2.1.2 Physical, Chemical and Biological	
Factors.....	9
2.1.2.a PRIMARY TREATMENT.....	10
2.1.2.b SECONDARY TREATMENT.....	12
2.1.2.c DIGESTION.....	16
2.1.2.d COMPOSTING.....	17
2.2 SOURCES, FATE AND IMPACT OF METALS.....	20
2.2.1 Non-industrial Sources.....	20
2.2.2 Hazards Posed by Metals.....	24
2.2.3 Individual Metals.....	25
2.2.3.a CADMIUM.....	25
2.2.3.b COPPER.....	27
2.2.3.c CHROMIUM.....	28
2.2.3.d LEAD.....	29
2.2.3.e NICKEL.....	31
2.2.3.f ZINC.....	32
2.2.3.g IRON AND ALUMINUM.....	32
2.2.3.h MANGANESE.....	33
2.2.3.i MOLYBDENUM.....	34
2.2.3.j SELENIUM.....	34
2.2.3.k BORON.....	35
2.2.4 Environmental Pathways.....	36
2.3 REGULATIONS.....	36
2.4 MANAGEMENT OPTIONS.....	41
2.4.1 Pretreatment.....	41
2.4.2 Additional Treatment.....	43
2.4.3 Land Disposal Options.....	46
III. EXPERIMENTAL METHODS AND MATERIALS.....	49
3.1 FACILITY DESCRIPTION.....	49
3.2 SAMPLE COLLECTION.....	53

3.3	SAMPLE PROCESSING AND ANALYSIS.....	58
IV.	RESULTS AND DISCUSSION.....	64
4.1	BATCH COMPOSTING STUDIES.....	64
4.2	STATISTICAL ANALYSIS.....	79
4.3	STORED COMPOST ANALYSES.....	82
4.4	VARIABILITY OF THE DATA.....	88
V.	CONCLUSIONS AND RECOMMENDATIONS.....	92
5.1	CONCLUSIONS.....	92
5.2	RECOMMENDATIONS.....	93
	REFERENCES.....	94
	APPENDICES.....	101
APPENDIX A	SUMMARY OF SELECTED STATES' REGULATIONS ON LAND APPLICATION.....	101
APPENDIX B	ATOMIC ABSORPTION SPECTROPHOTOMETRY ANALYTICAL CONDITIONS.....	110
APPENDIX C	DATA FROM HEAVY METALS ANALYSES.....	113
APPENDIX D	COEFFICIENTS OF VARIATION OF METALS ANALYSES DATA.....	125

LIST OF TABLES

<u>Table Number</u>	<u>Title</u>	<u>Page</u>
1	METAL CONCENTRATIONS IN WWTP INFLUENTS AND EFFLUENTS.....	7
2	RANGE OF METAL CONCENTRATIONS IN SLUDGE.....	8
3	PERCENT REMOVAL OF METALS BY UNIT PROCESS.....	11
4	METAL CONCENTRATION OF COMPOST (AND PARENT SLUDGE).....	21
5	PERCENTAGE OF METAL LOADING FROM RESIDENTIAL SOURCES.....	23
6	CONCENTRATIONS OF METALS IN URBAN RUNOFF.....	23
7	HEAVY METALS MASS FLOW FROM RESIDENTIAL SOURCES.....	23
8	METALS AND ENVIRONMENTAL PATHWAYS STUDIED FOR DEVELOPMENT OF REGULATIONS.....	37
9	MAXIMUM CUMULATIVE METAL LOADINGS ON LAND.....	39
10	BATCH COMPOSTING SCHEDULE.....	65
11	MEAN AND MEDIAN VALUES OF PERCENT CHANGE IN SLUDGE METALS CONCENTRATIONS DURING COMPOSTING.....	72
12	RESULTS OF METALS ANALYSES OF LIQUID SAMPLES.....	74
13	RESULTS OF METAL ANALYSIS OF UNCONDITIONED SLUDGE.....	78
14	RESULTS OF ANALYSIS OF VARIANCE OF BATCH COMPOSTING DATA.....	81

<u>Table Number</u>	<u>Title</u>	<u>Page</u>
15	PERCENT DIFFERENCE BETWEEN AVERAGE METALS CONCENTRATIONS IN BATCH COMPOST AND STORED COMPOST SAMPLES.....	87



LIST OF FIGURES

<u>Figure Number</u>	<u>Title</u>	<u>Page</u>
1	PROCESS DIAGRAM OF COMPOSTING FACILITY.....	51
2	DIAGRAM OF SAMPLING PROGRAM.....	56
3	SAMPLE PROCESSING AND ANALYSIS FLOW DIAGRAM.....	59
4	AVERAGE CADMIUM CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES.....	66
5	AVERAGE CHROMIUM CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES.....	66
6	AVERAGE COPPER CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES.....	67
7	AVERAGE NICKEL CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES.....	67
8	AVERAGE LEAD CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES.....	68
9	AVERAGE ZINC CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES.....	68
10	CHANGE IN SLUDGE METALS CONCENTRATIONS DURING COMPOSTING.....	70
11	AVERAGE CADMIUM CONCENTRATIONS IN COMPOST SAMPLES.....	83
12	AVERAGE CHROMIUM CONCENTRATIONS IN COMPOST SAMPLES.....	83
13	AVERAGE COPPER CONCENTRATIONS IN COMPOST SAMPLES.....	84
14	AVERAGE NICKEL CONCENTRATIONS IN COMPOST SAMPLES.....	84
15	AVERAGE LEAD CONCENTRATIONS IN COMPOST SAMPLES.....	85

<u>Figure Number</u>	<u>Title</u>	<u>Page</u>
16	AVERAGE ZINC CONCENTRATIONS IN COMPOST SAMPLES.....	85

CHAPTER I

INTRODUCTION

Heavy metals can cause several problems in municipal wastewater treatment systems. High concentrations of metals in wastewater are toxic to biological treatment processes. Metals discharged in the treated effluent can cause environmental damage. Metals in wastewater sludges can be damaging to the environment as well.

Biological treatment processes remove metals from the liquid stream and concentrate them in the solid stream. Heavy metals which cannot be detected in the influent wastewater can be concentrated to measurable levels in the sludge (EPA, 1979b). Metals levels in the sludge may be three to four orders of magnitude higher than in the influent wastewater (Olthof and Lancy, 1978). In the past, this effect has been considered totally beneficial since it removed the metals from the treated wastewater. Sludge disposal was typically by incineration or landfilling, neither of which was limited by the metals content of the sludge.

In recent years, restrictions on incineration of wastes and decreases in available landfill space along with increasing disposal costs have limited sludge disposal options for many

cities and towns. As a result, many municipalities are seeking alternative methods of sludge disposal.

One alternative method of disposal being employed is land application of sludge. Sludge is applied to land as a fertilizer or soil conditioner. Land application of sludge may be used for agricultural, forestry, nursery, or turf crops; reclamation of severely disturbed land; or for recreational or roadside land development.

In many areas, particularly in the Northeast, there is insufficient land available for sludge application. As a result, some municipalities are considering composting the sludge prior to disposal. Currently in Massachusetts there are 23 composting facilities either in operation or under development (Goldstein, 1987).

Composting is an aerobic biological stabilization process carried out at thermophilic temperatures resulting from biological activity. This process converts the sludge into a stable, dry, inoffensive humus-like material (Haug, 1980).

Composted sludge, like raw sludge, may be disposed of by land application. Composting sludge, however, has a number of advantages. Composted sludge has a lower moisture content, less volume, and is more stable than raw sludge. Composted sludge is easier to store, handle, and transport than raw sludge. Composted sludge has fewer pathogens and less odor than raw sludge making it more suitable for sale and distribution to individual users as a

soil amendment. These advantages increase the number of available disposal options. Composted sludge may also be used as landfill cover (Parr, et al., 1978, EPA, 1979b).

Most states and the federal government regulate land disposal of sludge and composted sludge primarily on the basis of it's heavy metals content. Massachusetts regulations (310 CMR 32) control disposal based on the concentrations of cadmium, chromium, copper, mercury, nickel, lead, zinc, boron, and molybdenum in the sludge or compost. These restrictions limit available disposal sites and create higher land requirements for sludge disposal.

When evaluating the feasibility of sludge composting, the metals content of the final product is an important parameter. Typically, initial predictions of final metals concentrations are based on rules of thumb and limited data from previous projects. There is little information in the literature examining the factors affecting the fate of heavy metals during composting.

This study was undertaken to examine and quantify the variations in heavy metals content of municipal sludge and sludge compost. This objective was accomplished in two steps. First, a detailed literature review was completed examining information or collected data on heavy metals in wastewater and wastewater sludges. The specific topics addressed were:

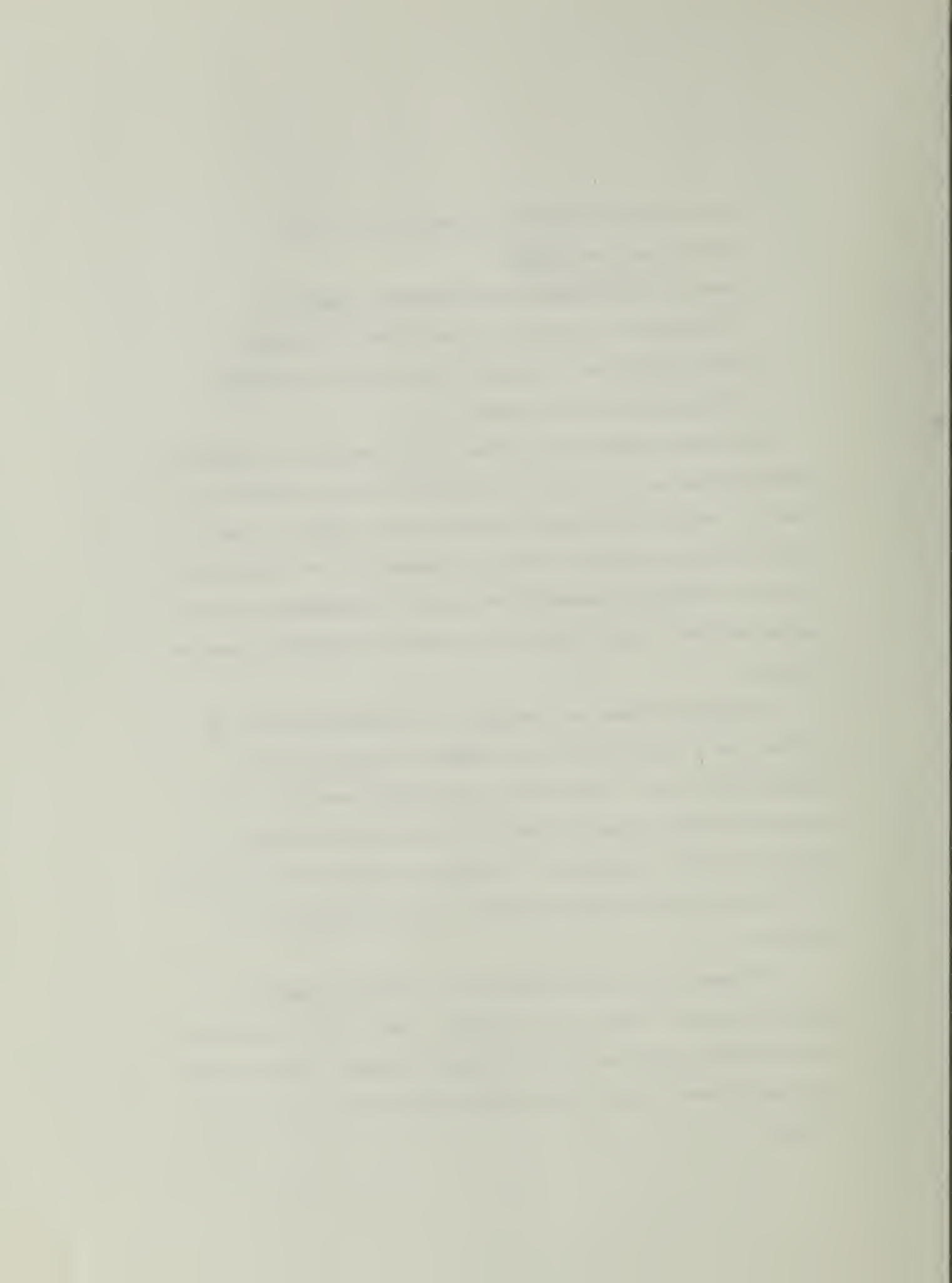
1. Which metals are typically found in wastewaters and sludges and at what concentrations?
2. What are the sources of the metals?

3. What factors affect the incorporation of the metals into the sludge?
4. What are the potential environmental impacts of the metals as a result of land disposal of sludge?
5. What options are available to deal with the problems caused by metals in sludge?

The second step was to perform a field study of an operating sludge composting facility. The objective of this study was to produce a statistically sound database of the change in sludge metals concentrations as a result of composting. Once sufficient data are available documenting the effect of composting on metals concentrations, future studies can examine the specific processes involved.

A sampling program was designed to intensively sample and analyze the sludge entering, and compost exiting the batch composting process. The sampling and analysis were done to accurately characterize the quality of each batch of sludge, before and after composting. Statistical analysis of the data was performed to provide further support for the validity of the results.

Six heavy metals were selected for analysis: cadmium, chromium, copper, nickel, lead and zinc. These metals are present in measurable quantities in all municipal sludges. They are also included in most states' regulations on land application of sludge.



CHAPTER II

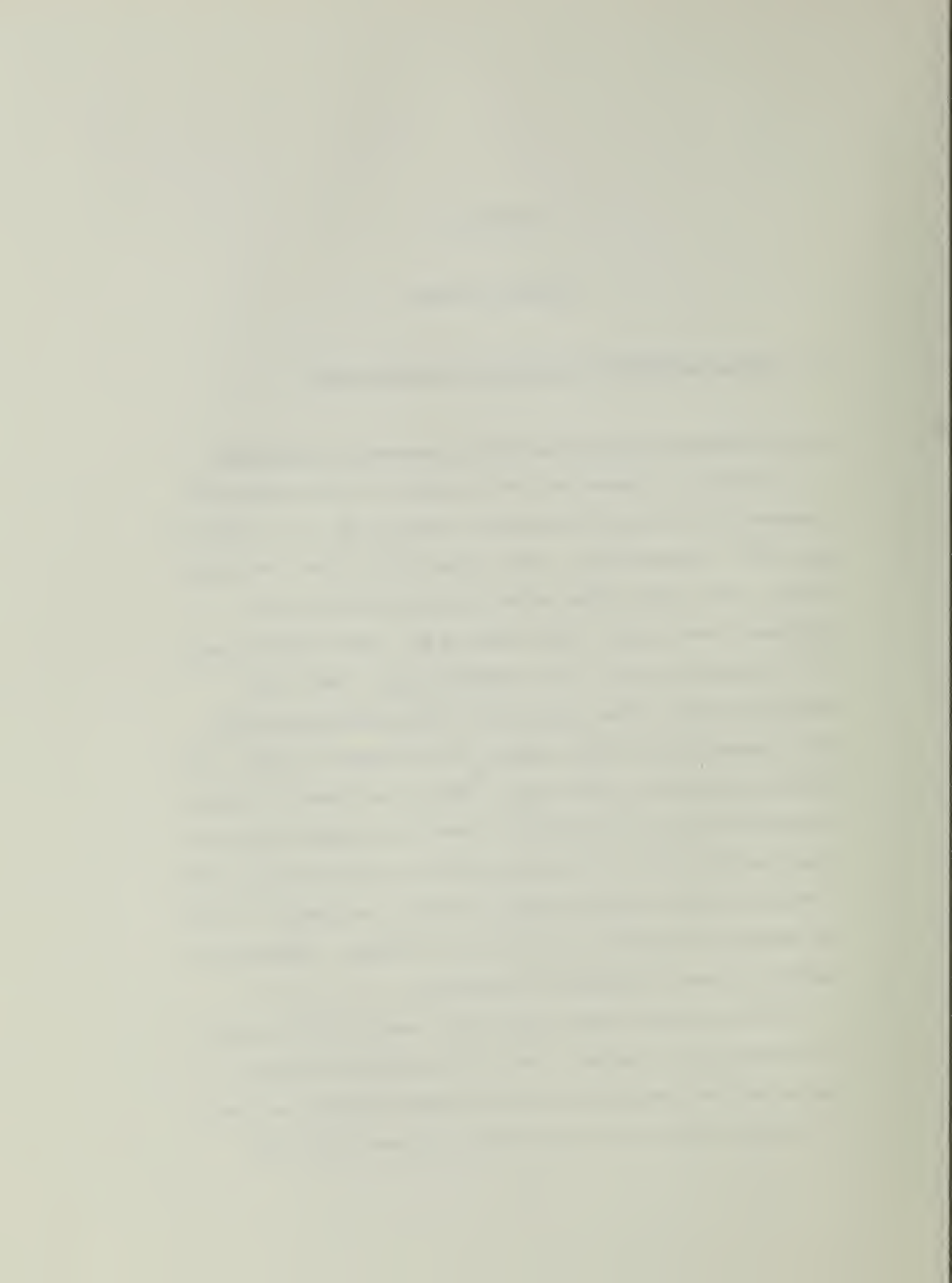
LITERATURE REVIEW

2.1 METALS IN MUNICIPAL WASTEWATER TREATMENT PLANTS

2.1.1 Typical Levels and Variability: Wastewater and Sludges

A number of studies have been conducted to characterize the composition of municipal wastewaters (Brown et al., 1973, Klein et al., 1974, Gurnham et al., 1979, Lester et al., 1979, Stoveland et al., 1979, Hanley, 1985, Aulenbach et al., 1987), POTW effluents (Brown et al., 1973, Klein et al., 1974, Lester et al., 1979, Stoveland et al., 1979, Aulenbach et al., 1987), and municipal sludges (Brown et al., 1973, Bastian and Whittington, 1976, Sommers et al., 1976, Sommers, 1977, Olthof and Lancy, 1978, Sterritt and Lester, 1981a, Hanley, 1985). The elements selected for analysis differed from study to study, but certain ones were common to all studies. Furr et al. (1976) and Mumma et al. (1984) conducted the most detailed studies of metals in sludge. Furr et al. analyzed sludge from 16 cities for 68 elements. Mumma et al. analyzed 30 sewage sludges for 59 elements.

While individual values vary widely, mean values for metals in sludge are more constant. EPA (1982) sampled 50 treatment plants 24 hours a day for at least six days, measuring the levels of priority pollutants in the influent, effluent and sludge.



Fricke et al. (1985) compared the mean values in sludge from this study with those from other available municipal sludge data bases. The values obtained by EPA for metals in sludge were within approximately a factor of two of the database values.

Olthof et al. (1978) studied literature values for metals' levels in wastewater treatment processes. They developed accumulation factors for metals in sludge. These are ratios of metals in sludge to metals removed from wastewater (expressed as mg metal/kg dry wt sludge per mg/liter metal removed from the wastewater). Values obtained ranged from 3270 to 24700. Digested sludge had higher values than raw sludge. They concluded that as a rule of thumb, 10,000 was a reasonable estimate.

Table 1 presents some typical values from the literature for the composition of raw wastewater and treated effluent. Table 2 presents ranges of metals' levels measured in sludges. The variability in metal content of sludges from city to city is a reflection of the variability of sources of metals entering the treatment plants (Sommers et al., 1976). For an individual city, it is a function of influent concentration.

Sommers et al. (1976) examined the variability of the composition of sludge. The coefficient of variation (standard deviation as a percent of the mean) for the metals studied ranged from 32% to 72% for studies conducted within a city and from 77% to 146% for studies of variability between cities. According to

TABLE 1. METAL CONCENTRATIONS IN WWTIP INFLUENTS AND EFFLUENTS (micrograms per liter)

Reference		Al	As	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Zn
Hanley, 1985	influent	865	--	--	0	30	230	1600	70	170	0.4	20	--	10	200
	effluent	200	--	--	0	10	65	290	40	95	0.1	0	--	0	90
Brown et al. 1973	influent	--	--	--	18	59	170	--	160	--	0.6	--	--	--	353
	effluent	--	--	--	16	13	67	--	92	--	0.5	--	--	--	182
Yost and Wukasch, 1983	influent	--	--	--	33	786	168	17300	51	--	--	115	--	--	2070
	effluent	--	--	--	6.3	16.7	25.2	335	2.6	--	--	81.2	--	--	233
Aulenbach et al., 1987	influent	2006	7.6	0.5	7.6	182	392	--	872	--	0.3	1000	10.8	23.4	580
	effluent	534	7.5	--	0.9	18.6	65.5	--	150	--	0.2	--	10.2	2.5	300

TABLE 2 RANGE OF METAL CONCENTRATIONS IN SLUDGE (ppm)

Metal	Reference					
	Sommers (1977)		Solotto and Farrell (1972)		Bastian & Whittington (1976)	
	Range	Avg	Range	Avg	Range	Avg
Al	---	---	7750-36000	17360	---	---
As	6-230	43	---	---	10-50	9
Ba	---	---	100-4010	1360	nd-3000	1460
Be	---	---	1.2-6.5	2.5	---	---
B	4-760	77	3-1490	46	200-1430	430
Cd	3-3410	110	1-500	264	nd-1100	87
Cr	10-99000	2620	100-11000	2280	22-30000	1800
Co	1-18	5.3	---	---	nd-800	350
Cu	84-10400	1210	10-16000	1650	45-16030	1250
Fe	---	---	10900-60000	30650	---	---
Pb	13-19700	1360	180-7520	1890	80-2600	1940
Mn	18-7100	380	60-6040	976	100-8800	1190
Hg	0.5-10600	733	---	---	0.1-89	7
Mo	5-39	28	2-1290	254	---	---
Ni	2-3520	320	30-3000	372	nd-2800	410
Ag	---	---	80-500	195	nd-960	225
Sr	---	---	---	260	nd-2230	440
Sn	---	---	500-700	600	---	---
Ti	---	---	1000-20000	14200	---	---
V	---	---	320-10000	5200	nd-2100	510
Zn	101-27800	2790	500-11000	4040	51-28360	3483
Zr	---	---	100-5000	2030	---	---

nd-not detected

the studies conducted within individual cities, zinc, nickel, lead, and copper were moderately variable (C.V. 25-50%), while cadmium was highly variable (C.V.>50%). Doty et al. (1977) sampled six plants on a biweekly basis for one year. The coefficients of variation for the metals studied ranged from 21-47%.

Sommers et al. recommends sampling every two to three months for a year to characterize sludge composition prior to land application. Doty et al. concluded that three to five biweekly samples are sufficient. EPA (1983) recommends taking weekly samples for five weeks or more until the average value for the element being analyzed is within the 95 percent confidence interval.

2.1.2 Physical, Chemical and Biological Factors

Metals removal from wastewater and incorporation into sludge occurs primarily through two physicochemical processes: precipitation and adsorption. Settling processes dominate in primary treatment (Hanley, 1985). Metals removed in primary treatment are in the insoluble form or are adsorbed to organic solids or to iron or manganese oxyhydroxide particles (Oliver and Cosgrove, 1974). Soluble metals and metals associated with non-settleable particles are discharged to secondary treatment (activated sludge). In the activated sludge process, metals are removed in two ways. Particulate metals are enmeshed in the biological flocs and settled out. Metal ions in solution are

adsorbed onto microbial surfaces or onto extracellular polymers produced by the microorganisms (Lester, 1983). Adsorption sites in the biomass may be surface hydroxyl groups (hexose and pentose molecules on neutral polysaccharides), surface carboxyl groups on anionic polymers (Stoveland and Lester, 1980), or phosphoryl, carboxyl, sulphhydryl and hydroxyl groups of membrane proteins and lipids and of cell wall structural components (Nelson et al., 1981). Table 3 gives literature values for percent removal of metals by treatment process.

2.1.2.a PRIMARY TREATMENT

The factors that affect metal removal in primary treatment process are the efficiency of suspended solids removal and the chemical species of the metal. Suspended solids removal is affected by basin design, surface loading rate, flow rate and influent suspended solids concentration. The chemical species is dependent upon the metal concentration, COD (a measure of dissolved organic carbon), hardness, alkalinity and pH of the influent wastewater (Lester, 1983).

The percent removal of metals in primary treatment can vary widely temporally at a single plant. The ratio of day to night metal loading can be as high as 8:1. There is no evidence of correlation between influent concentration and percent removal except for cadmium. The percent removal of cadmium decreases at increased influent concentrations (Lester, 1983). Rossin et al.

TABLE 3. PERCENT REMOVAL OF METALS BY UNIT PROCESS

Reference	Al Cd Cr Co Cu Fe Pb Hg Mn Ni Zn										
	Al	Cd	Cr	Co	Cu	Fe	Pb	Hg	Mn	Ni	Zn
<u>Primary Treatment</u>											
Oliver and Cosgrove, 1974	--	60	55	50	33	49	66	60	33	15	54
Hanley, 1985	42	--	17	--	7	21	29	20	0	0	30
Lester <u>et al.</u> , 1979	--	72	--	--	70	--	73	--	--	--	--
Stoveland <u>et al.</u> , 1979	--	--	51	--	--	--	--	--	--	23	74
Brown <u>et al.</u> , 1973	--	25	36	--	70	--	59	54	--	--	68
Hannah <u>et al.</u> , 1986	--	12	7	--	19	--	30	--	--	4	--
<u>Activated Sludge</u>											
Oliver and Cosgrove, 1974	--	50	54	--	60	--	79	--	--	1	50
Hanley, 1985	84	--	99	--	82	74	67	94	29	55	60
Lester <u>et al.</u> , 1979	--	63	--	--	79	--	73	--	--	--	--
Stoveland <u>et al.</u> , 1979	--	--	33	--	--	--	--	--	--	61	78
Brown <u>et al.</u> , 1973	--	11	78	--	61	--	43	--	--	--	48
Hannah <u>et al.</u> , 1986	--	24	82	--	82	--	65	--	--	43	--
<u>Trickling Filter</u>											
Hanley, 1985	55	--	33	--	32	60	14	41	17	73	33
Hannah <u>et al.</u> , 1986	--	28	52	--	60	--	48	--	--	30	--
<u>Extended Aeration</u>											
Hanley, 1985	70	--	77	--	82	72	40	37	28	50	39
<u>Aerated Lagoon</u>											
Hannah <u>et al.</u> , 1986	--	--	71	--	74	--	58	--	--	35	--

1870

Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Feb	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Mar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Apr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jun	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jul	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Aug	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Sep	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Nov	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Dec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

(1983) found that at a constant influent metal concentration the percent removal of cadmium, chromium, copper and zinc decreased as flow rate increased. Removal of lead was higher at higher flow rates. Brown et al. (1973) found that percent removal decreased when digester liquor was recirculated through primary treatment. According to Lester (1983), the order of removal in primary treatment, on average, is $Pb > Cu > Zn > Cd > Cr > Ni$.

2.1.2.b SECONDARY TREATMENT

In secondary treatment uptake of metals by the biomass occurs in two stages. Rapid uptake of metals occurs in the first three to ten minutes. During this stage large amounts of metals are adsorbed by the biomass (Chen et al., 1974, Nelson et al., 1981). The second stage is a period of slow, continuous uptake. During the second stage, almost complete equilibrium between the adsorbed metals and metals in solution is approached after three hours. Complete equilibrium is achieved after approximately two weeks (Nelson et al., 1981).

Several studies have found a correlation between the concentration of some metals in the influent to the activated sludge process and the amount of those metals removed in the sludge. This relationship can be fitted to Freundlich or Langmuir isotherms (Neufeld and Hermann, 1975, Gould and Genetelli, 1978, Nelson et al., 1981, Sterritt et al., 1981).

Metal removal by activated sludge varies widely between treatment plants as well as for different metals. Values in the literature for metal removal range from 1 to 82% (Oliver and Cosgrove, 1974, Nelson et al., 1981, Hannah et al., 1986). Brown and Lester (1979) divided the factors which influence metal removal into three groups: process parameters, physical/chemical factors and biological factors. Process parameters are sludge volume index, sludge age, suspended solids removal, dissolved oxygen concentration and settling time. Physical/chemical factors are temperature, pH, metal ion concentration, metal solubility, metal valency, concentration of complexing agents and particle size. The biological factor is the concentration of extracellular polymers. Sterritt et al. (1981) state that sludge volume index, MLSS, effluent suspended solids and effluent COD affect metal removal. In the activated sludge process these are all a function of sludge age. Nelson et al. (1981) concluded that system pH is the single most important factor influencing chemical speciation of metals and their distribution between bacterial solids and solution phases.

Several studies have examined the effect of sludge age on metal removal by activated sludge (Nelson et al., 1981, Sterritt et al., 1981, Sterritt and Lester, 1981b, Rossin et al., 1982). In general, metal uptake by the sludge increases with sludge age. Maximum uptake occurred at a sludge age of 12 to 15 days. Nelson et al. (1981) state that this is due to increased amounts of

extracellular polymers. Rossin et al. (1982) speculate that increased MLSS is not the only factor. Sterritt et al. (1981) and Stoveland and Lester (1980) note that effluent COD decreases as sludge age increases. Maximum metals removal coincided with minimum effluent COD at a sludge age of 12 days. Minimum metal removal was at a sludge age of six days which coincided with maximum effluent COD. These results suggest that soluble organic compound compete with the sludge for the adsorption of metals. Failure of the biomass to degrade these compounds resulting in poor effluent quality may result in decreased metal removal efficiency (Sterritt et al., 1981).

Values for average removal of individual metals indicate that some metals are typically removed more efficiently than others. Different metals are removed to various degrees by the different processes in primary and secondary treatment.

Literature values indicate that nickel is removed least efficiently of all the metals, usually less than 40%. Stoveland and Lester (1980) attribute this to a high affinity for soluble ligands. Cantwell et al. (1982) found no detectable free nickel in raw sewage; all was complexed. Rossin et al. (1982) state that nickel removal may only be by sedimentation of precipitated nickel. Chen (1974) found that nickel forms very little precipitate and that most precipitated nickel exists as particles less than eight microns, whereas most cadmium, chromium and copper are associated with larger particles that settle more readily.

Gould and Genetelli (1984) state that adsorption of nickel by activated sludge may be site specific.

Some metals are removed primarily through precipitation rather than adsorption. Sterritt et al. (1981) concluded that lead and trivalent chromium are removed by precipitation while other metals are removed by adsorption. Rossin et al. (1983) found that removal of lead is related to suspended solids removal, indicating that lead is primarily in an insoluble form in wastewater. In the activated sludge process, as dissolved oxygen decreases, hexavalent chromium is reduced to the trivalent form which then precipitates (Brown et al., 1973, Stoveland and Lester, 1980).

Addition of chelating agents reduces uptake of metals by sludge (Cheng et al., 1975). These may be organic ligands, nitriloacetic acid (NTA), which is used in detergents, ethylenediaminetetraacetic acid (EDTA), which is used in industry, or others (Brown and Lester, 1979). Perry et al. (1984) found that NTA was 90% degraded after nine to thirteen days in the activated sludge process, but that metal interaction with NTA interferes with biodegradation. Cheng et al. (1975) found that the order of strength of competition for metal ions is: sludge<glycine<oxalate<NTA<EDTA.

Adsorption of various metals by activated sludge can vary depending on the concentrations of the other metals present. According to Lester (1983), activated sludge is a dynamic process;

the influent metal concentrations are continually changing hence equilibria between the phases of the metals are constantly shifting. Gould and Genetelli (1984) found that metals could be "salted out" of sludge by addition of other metals except nickel. They concluded that the order of strength of competition was $\text{Cu} > \text{Cd} > \text{Zn} > \text{Ni}$. Sterritt and Lester (1981b) found the order of affinity of metals for sludge to be $\text{Cr} > \text{Cd} > \text{Ag} > \text{Pb} > \text{Zn} > \text{Cu} > \text{Ni}, \text{Co}, \text{Mn}, \text{Mo}$. Cheng et al. (1975) obtained similar results but also found that the order varies with pH. Sterritt et al. (1981) concluded that while some metals may compete for adsorption sites, competition for binding sites is generally negligible.

2.1.2.c DIGESTION

During the digestion process some of the metals in sludge will solubilize (Bloomfield and Pruden, 1975). Metals in digester supernatants can be 10 to 300 times the influent concentration (Brown et al., 1973). If the supernatant is recycled through the treatment plant it can be a significant source of metals in the sludge.

Any sulfate that enters the digester will be reduced to sulfide. Excess sulfide will precipitate the soluble metals. Typically less than one percent of the sulfate in the wastewater ends up in the digester. This is not enough to precipitate all the soluble metals present in the supernatant (Masselli et al., 1967).

During digestion the mass of the sludge is reduced as organics are degraded in the stabilization process. Digested sludges are typically higher in metals than raw or undigested sludges from which they derive because metals are concentrated during digestion (Parr et al., 1978).

2.1.2.d COMPOSTING

Composting is the aerobic thermophilic decomposition of the organic constituents in sludge producing a relatively stable, inoffensive humus-like material (Ehreth and Walker, 1977). During the composting process temperatures between 55 and 65 degrees Celsius are attained, destroying pathogens and driving the evaporation of water. Volatile organics are reduced to carbon dioxide and water as the sludge is stabilized (EPA, 1979b).

In the composting process, sludge is mixed with organic amendments (such as wood chips). These amendments act as a bulking agent, increasing the porosity of the mix and reducing the moisture content. The amendments also can be added to supply a source of limiting nutrients, such as carbon. The mixture is aerated by repeatedly turning the pile or by forcing air through the pile. In some processes the bulking agent is separated from the compost after composting and recycled for subsequent use.

There is very little information in the literature concerning the fate of metals during composting. The concentrations of heavy

metals in the final compost will depend on several factors. These are:

1. the concentrations of heavy metals in the parent sludge,
2. the loss of metals through leaching,
3. increase in the organic content of the compost due to addition of organic amendments,
4. decrease in the organic content of the compost due to degradation of organics,
5. addition of metals in the composting amendments and
6. physical/chemical interactions between the compost and the bulking agent.

Metals are essentially conserved during composting; less than one percent are lost through leaching (Obrist, 1987). The concentration of metals in compost will be determined primarily by the percent change in organic matter during composting and any metals that may be added to the sludge in the composting amendments (Higgins, 1984, Higgins et al., 1980, Parr et al., 1978).

The heavy metals concentrations of compost will vary with the composting practice, the extent of digestion and the amount of amendments blended with the sludge (Black and Veatch, 1987). During the composting process volatile organics are lost from the sludge as the organic matter is degraded. Approximately 40% of the initial total solids will be degraded due to organic matter destruction. This will result in a corresponding increase in the

final metals concentration (Higgins et al., 1980). Parent sludges that have been previously digested will have higher metal concentrations than undigested sludges. Degradation of organics during the composting process will be less than for undigested sludges (Parr et al., 1978). Organic amendments such as woodchips, peanut hulls or leaves can provide a dilution effect lowering the metals concentration below that of the parent sludge (Alpert et al., 1981, Mosher and Anderson, 1977, Parr et al., 1978).

The composting amendment can directly influence the metals content of the final compost. If the amendment is not separated from the compost at the end of the process, then any metals in the amendment will increase the mass of metals in the compost. The use of recycled compost that contains metals as a bulking agent is an example (Higgins, 1984).

Physical and chemical interactions between amendments and sludge can affect the metals content of the compost. Shredded tires are used as a bulking agent. They contain metals, primarily iron and zinc, which become incorporated into the compost raising the metals levels (Higgins, 1984).

Sorption of sludge metals onto the amendments has not been specifically studied. In a related study, however, Benson (1980) examined the sorption of metals in landfill leachate onto sawdust. He determined that the sawdust had a fixing capacity of 113

meq/kg. Part of this fixing capacity was due to cation exchange reactions and part was due to complexation reactions.

Table 4 gives metal concentrations for several composts and their parent sludges.

2.2 SOURCES, FATE AND IMPACTS OF METALS

Non-industrial Sources

Sources of metals in sludge include background levels in the domestic water supply, domestic additions, industrial discharges, surface runoff and sewer infiltrations (Wood and Tchobanoglous, 1975).

Klein et al. (1974) studied the sources of cadmium, copper, chromium, nickel and zinc in New York City wastewater. They concluded:

1. Except for nickel at 62%, the electroplating industry does not contribute the major portion of the metals in the wastewater.
2. Other industries contribute less than 9% of metals.
3. Residential contribution of metals varies from 25-49%. Residential discharge of copper, cadmium, and zinc is considerably greater than industrial discharge.
4. Water distribution systems contribute 67% more copper than electroplaters and half as much zinc.
5. Storm water runoff contributes more copper and zinc than electroplaters and about 10% of the other metals.

TABLE 4 METAL CONCENTRATION OF COMPOST (AND PARENT SLUDGE)
(Parts Per Million)

Ref.	Amends.	Cd	Cr	Cu	Fe	Ni	Pb	Zn
(a)	wood chips	8 (10)	-- --	300 (420)	-- --	55 (85)	290 (425)	770 (980)
(a)	wood chips	9 (19)	-- --	250 (725)	-- --	-- --	320 (573)	1000 (1760)
(b)	shredded tires + recycled compost	39 (35)	-- --	633 (520)	20177 (8096)	85 (86)	513 (439)	2200 (1043)
(b)	shredded tires + wood shavings	36 (35)	-- --	591 (520)	18284 (8096)	77 (86)	489 (439)	1950 (1043)
(c)	wood chips	1.5 (4)	30 (90)	140 (600)	-- --	7 (50)	43 (80)	360 (600)
(c)	brush chips	0.5 (2.4)	96 (870)	60 (340)	-- --	17 (13)	74 (230)	80 (390)
(d)	bark	0.7 (4.8)	17 (28.6)	83.9 (278)	4173 (7550)	25.2 (22.6)	118 (408)	154 (453)

(a) Parr, et al., 1978

(b) Higgins, 1984

(c) Donovan, et al., 1985

(d) Mosher and Anderson, 1977

Yost and Wukasch (1983) studied the metals contributions by industrial and residential discharges in Kokomo, Indiana. Residential inputs of these metals did not exceed 7% of the industrial inputs. Davis and Jacknow (1975) investigated metals in urban wastewater. They found that residential loadings supplied 19 to 63% of the metals studied. Table 5 gives values for the percent contribution of metals by residential sources to municipal wastewater. Table 6 gives measured values for metals in urban runoff.

Gurnham et al. (1979) conducted a detailed analysis of the sources of metals in domestic wastewater. Metals concentrations and loadings for sources such as household products, foodstuffs, runoff, tapwater and soils were studied. Table 7 gives per capita mass loading of metals by various residential sources.

Data from some treatment plants suggest that the water supply system is the major source of metals in wastewater (Brown, 1985, Davis and Jacknow, 1975, Fair et al., 1968, Sommers et al., 1976). Corrosion of distribution piping and home plumbing along with the use of corrosion inhibitors are sources of cadmium, copper, zinc, and lead. This occurs with low alkalinity, low pH surface waters or low pH, high dissolved CO₂ groundwaters (Brown, 1985).

Brown (1985) estimated the minimum concentrations of metals in tap water that would result in metal levels in sludge in excess of land application guidelines. He compared these values with

TABLE 5 PERCENTAGE OF METAL LOADING FROM RESIDENTIAL SOURCES

Metal	Reference	
	Davis and Jacknow (1975)	Klein <u>et al.</u> (1974)
Cd	63	49
Cr	23	28
Cu	96	47
Ni	63	25
Pb	19	--
Zn	32	42

TABLE 6 CONCENTRATIONS OF METALS IN URBAN RUNOFF (mg/l)

Cd	0.025
Cr	0.16
Cu	0.46
Ni	0.15
Zn	1.6

Source: Klein et al. (1974)

TABLE 7 HEAVY METAL MASS FLOW FROM RESIDENTIAL SOURCES
(micrograms per capita per day)

Metal	Tap Water	Foods	Commodities	Total
Cd	518	482	81	842
Cr	845	364	662	1,871
Cu	7,580	2,909	510	10,996
Pb	2,612	331	272	3,215
Hg	110	27	7.5	144
Ni	4,590	699	23,449	28,738
Zn	12,204	11,953	738	24,895

Source: Gurnham et al. (1979)

data for drinking water in Boston and Seattle. The reported concentrations of copper in these waters were above the calculated value.

2.2.2 Hazards Posed by Metals

There is some variation in the literature concerning precisely which metals present the more serious hazards. Chaney (1974), states that the elements in sludge and effluent that are potential hazards to plants or the food chain are B, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn. Elinder and Kessler (1984) state that possibly toxic elements are Al, V, Co, Ni, Mo, Sn, and Sb, while elements causing major health problems are Hg, Pb, Cd, and As. Dean and Seuss (1985) concluded that with the exception of cadmium, heavy metals in sludge are not expected to affect human health through accumulation in food and fodder plants. EPA (1976) identified those elements posing relatively little hazard as Mn, Fe, Al, Cr, As, Se, Sb, Pb, and Hg. Elements posing a potentially serious hazard were Cd, Cu, Mo, Ni, and Zn. Brown and Lester (1979) identify metals of concern as Cr, Mn, Fe, Co, Cu, Zn, Mo, Ag, Hg, Cd, and Ni. Gleason et al. (1984) note that elements such as Cu, Zn, Mo, and Fe, present in sewage sludge added to agricultural soils at agronomic rates can help alleviate trace metal deficiencies in plants. An increase in plant trace metal content following sewage sludge application can also reduce the need for supplements of such elements as Se and Mo in animal diets.

Zenz et al. (1975), commenting on proposed EPA regulations to control land application of sludge, cited several studies to argue that the regulations were too restrictive. They stated that:

1. The metals may be precipitated to sparingly soluble inorganic forms that are not available to plant growth.
2. The metals are absorbed by organic matter reducing their activity.
3. Metals are held back by the soil-root barrier. The rejection of metals varies not only with species but even with strains.
4. Metals taken up by roots accumulate preferentially in the stems and leaves and are not translocated to the fruits or grains. Total metal uptake by young plants is a poor indication of the hazard to human food.
5. Metal toxicity usually inhibits growth before concentrations toxic to humans have been reached in the parts used for food.
6. Not all metals present in foods are assimilated into the body burden. Cadmium, for example, is rapidly excreted in the feces; only three to eight percent is slowly excreted and contributes to the body burden.

2.2.3 Individual Metals

2.2.3.a CADMIUM

It is widely agreed upon that cadmium is the element that poses the most serious health hazard in the food chain. Cadmium is readily taken up and accumulated by plants without phytotoxic effects (Chaney, 1974, Dean and Seuss, 1985). Chronic health effects may result through diet and cigarette smoking, which are the main routes of uptake for most people (EPA, 1979a).

Cadmium is not an essential element. It resembles zinc in its chemical and physical properties. The average dietary intake in non-polluted areas is 10-25 micrograms per day. Simultaneous intake of calcium, zinc or iron at low levels can increase cadmium absorption. Cadmium toxicity is affected by the quantity and quality of protein in the diet. Only about 5-6% of the cadmium in food or beverage is taken up by the body, but 50-75% of this amount is deposited in the liver and kidneys (Waldron, 1980). Long term exposure can result in kidney or liver damage (EPA, 1979a).

Cadmium is taken up by plants and translocated to other parts of the plant. Leafy vegetables and root crops accumulate cadmium in their tissues. Tobacco also accumulates cadmium, increasing the exposure of cadmium for smokers (EPA, 1979a).

Cadmium is found in low levels in rocks, soil and water (Waldron, 1980). The chemistry of cadmium in the soil is not well understood. It is apparently influenced by organic matter, clay content and type, hydrous oxide content, pH and redox potential (EPA, 1976). At pH levels between 6 and 9, metal hydroxide and

carbonate precipitates form, limiting cadmium availability (Dean and Seuss, 1985).

Industrial uses of cadmium include low melting alloys and solders, electroplating, batteries, and photoelectric cells. Cadmium is found as an impurity in zinc and superphosphate fertilizers. It is used in pigments, plastics, detergents, heating and lubricating oils and coal. Cadmium can be found in industrial, commercial and residential wastewaters as well as storm runoff (Dean et al., 1972, Klein et al., 1974, Waldron, 1980).

2.2.3.b COPPER

EPA (1976), classified copper as an element posing a potentially serious hazard. Chaney (1974), considers copper a significant food chain hazard. He also states that copper will cause severe plant injury before it reaches levels toxic to animals, except sheep. Dean and Seuss (1985), state that plants are an effective barrier against copper toxicity in animals.

Copper is an essential element for all organisms. Copper is essential to plants but it can be phytotoxic at higher concentrations. Under toxic conditions most copper remains in the roots-very little is transported to aerial portions. Sheep are the most susceptible to copper toxicity, followed by cattle, swine and poultry. Swine, sheep and cattle can accumulate copper in the liver. Molybdenum deficiency is antagonistic to copper toxicity.

Controlling molybdenum intake can prevent copper toxicity. High levels of copper in the diet are beneficial to swine and chickens. Debate concerning the addition of high levels of copper to animal diets has focused primarily on copper toxicity to plants grown on land treated with the animal wastes (EPA, 1976).

Copper is found in all soils, usually in the range of 10-80 ppm (Leeper, 1978). In soils it is associated with hydrous oxides of Mn and Fe, and soluble and insoluble complexes with organic matter (EPA, 1976). Copper toxicity usually occurs on acid soils. Control of pH can limit copper availability to plants (Dean and Seuss, 1985).

Sources of copper include pulp and paper, petroleum refining, and metal works industries. Other sources are soft drink production, laundries, food processing, algal control chemicals, residential wastewater and urban and rural runoff (Dean et al., 1972, Klein et al. 1974). Water supply systems can be a major source of copper. Water supplies can be high in copper due to erosion and corrosion of residential plumbing by low alkalinity waters (Brown, 1985).

2.2.3.c CHROMIUM

Chromium exists naturally either in trivalent or hexavalent forms. Hexavalent chromium is toxic to plants, animals and humans. Trivalent chromium is an essential element for all organisms--required for glucose metabolism (Elinder and Kessler,

1984). The main source of chromium in humans is food. Meat, whitefish, vegetables, unrefined sugar and vegetable oil are the largest sources to man (Waldron, 1980).

In the soil chromium(VI) is rapidly reduced to soluble chromium(III), which is converted to insoluble chromium(III). In the wastewater treatment process chromium(VI) is reduced to chromium(III) therefore sludge usually does not contain hexavalent chromium. Decomposition of sludge in soil is slow enough that there is no buildup of soluble chromium (EPA, 1976).

Dean and Seuss (1985), state that sludge borne chromium has no effect on plants or animals. EPA (1976), classified chromium as an element posing relatively little hazard. Sources of chromium include pulp and paper, chemical, and fertilizer manufacturing, petroleum refining, metal works, metal plating, glass, cement, asbestos and textile manufacturing, and steam generation (Dean et al., 1972). Chromium is also used in leather tanning, dyeing, photography and lithography (Waldron, 1980). Sources of chromium in commercial wastewater include bakeries, food processing, laundries and car washes.

2.2.3.d LEAD

Lead is a non-essential element that is capable of causing major health problems. The major sources of exposure in humans are food, wine, water, dust and paint (Elinder and Kessler, 1984).

Lead in sludge poses relatively little hazard. Lead forms insoluble compounds or is sorbed in soils becoming unavailable to plants. Soluble lead in the soil reacts with clay, phosphate, carbonate, hydroxide, sesquioxide and organic matter to greatly reduce solubility. Lead is taken up by plants in ionic form. Uptake decreases with pH, cation exchange capacity and available phosphorus (EPA, 1976). Any lead that is taken up by plants tends to remain in the roots. The shoots obtain very little soil lead (Dean and Seuss, 1985). The main source of lead in plants is atmospheric deposition (Waldron, 1980).

Other routes of lead transfer provide the only health risks to humans and animal. Direct ingestion of sludge or sludge amended soil by animals or humans is the most serious health risk. This may be due to direct soil ingestion by animals while grazing, ingestion by animals or humans of plants on which sludge or soil deposition has occurred, or pica soil ingestion by humans. About 90% of the lead deposited in the body is in the skeleton, so intake of lead through ingestion of animal products is not a major health risk to humans (Dean and Seuss, 1985).

Sources of lead include pulp and paper, chemical and fertilizer manufacturing, petroleum refining and metal works and battery manufacturing. Other sources include paints, dyes, solders, automobile and smelter emissions, corrosion of plumbing, food, soil and dust (Dean et al., 1972, Dean and Seuss, 1985, Waldron, 1980).

2.2.3.e NICKEL

Nickel is an essential element in animals that is found in nearly all soils, plants and waters. Soils typically contain 10-100 ppm nickel. In the soil, nickel is adsorbed onto hydrous oxides of iron or manganese or is strongly chelated by organic matter (EPA, 1976).

The only form of nickel known to cause systemic effects in humans is nickel carbonyl. Insoluble forms of nickel have been linked to respiratory cancer (Elinder and Kessler, 1985). Nickel in sludge or sludge fertilized crops fed to animals has not led to bioaccumulation. Nickel ingested by humans is relatively nontoxic except to persons who are sensitive to nickel (Dean and Seuss, 1985).

Nickel is not known to be essential to plants. It is toxic to plants at levels greater than 50 ppm. Chaney (1974) states that nickel will be phytotoxic before reaching levels hazardous in the food chain. Toxicity usually occurs on acid soils. Controlling pH will reduce nickel toxicity in plants (EPA, 1976).

Nickel is found in fossil fuels, batteries, alloys, inks and varnishes. The most significant route of exposure in humans is by dermal contact (wearing of jewelry). Concentrations in food vary up to approximately 6 ppm (Waldron, 1980). Sources of nickel in wastewater include pulp and paper and fertilizer manufacturing, petroleum refining, metal works, bakery wastes and runoff (Dean et al., 1972, Klein et al., 1974).

2.2.3.f ZINC

Zinc is essential for the functioning of various enzymes in all organisms. Zinc is commonly deficient in crops and is typically added with fertilizers. Normal plant levels range from 10 to 100 ppm. Higher levels in plants can be phytotoxic and can be a food chain hazard (Chaney, 1974, Elinder and Kessler, 1984). Toxicity in plants occurs at tissue concentrations of several hundred ppm. A wide margin of safety exists between normal dietary intake and toxic levels in birds and mammals (EPA, 1976).

In the soil, zinc is sorbed onto clay and hydrous iron oxides and chelated by organic matter. In general, if the pH of the sludge-treated soil is maintained at recommended levels, zinc should not be a serious hazard to plants or the food supply unless the sludge contains exceptionally high levels of zinc (EPA, 1976).

Sources of zinc include pulp and paper, chemical and fertilizer manufacturing, petroleum refining, metal works and steam generation (19). Other sources are fat rendering, food processing, soft drink manufacturing, dyeing and laundries (Klein et al., 1974).

2.2.3.g IRON AND ALUMINUM

Iron and aluminum are common elements in the soil. Most soils contain large amounts of iron and aluminum so that addition of sludges high in these elements will not significantly alter the

soil composition. Typically, iron and aluminum are not limiting factors in sludge application (EPA, 1976).

Iron and aluminum are soluble in the soil only at low pH or under reducing conditions. Aluminum toxicity in plants is common below pH 5.0. At pH above 5.5 iron and aluminum form sparingly soluble oxides and hydroxides. Iron is mobile in the soil solution in minute amounts chelated with organic anions. With good soil management practices, most iron and aluminum in the soil solution will rapidly precipitate out as hydroxides (EPA, 1976, Leeper, 1978).

Sources of iron and aluminum include chemical and fertilizer manufacturing, petroleum refining and metal works (Dean et al., 1972).

2.2.3.h MANGANESE

Manganese is an essential element. Like iron and aluminum, manganese is available in the soil only at low pH or under reducing conditions. At pH above 5.5 manganese forms insoluble tetravalent oxides or some stable organic complexes. Under these conditions manganese can be toxic to plants. Manganese may accumulate in plants if large amounts are present in the soil. High levels of soluble iron in the soil may induce manganese deficiency in plants. Typically, manganese is not a limiting factor in sludge application (EPA, 1976, Leeper, 1978).

2.2.3.i MOLYBDENUM

Molybdenum is an essential element in plants and animals. It is a cofactor in seven enzymes. In plants it is essential for nitrogen fixation and nitrate reduction (Le Gendre and Runnels, 1975). Molybdenum does not appear to be phytotoxic at high concentrations in plants (EPA, 1976).

Tolerance of animals to molybdenum varies with species and age. Excessive molybdenum in the diet of animals causes copper and phosphorus deficiencies. The condition is correctable with copper and phosphorus supplements. It is doubtful that molybdenum in sludge would present a serious health hazard to grazing animals except where forages from sites treated with sludge high in molybdenum form the major part of the animal diet (EPA, 1976).

In the soil molybdenum exists primarily in an anionic form. The soil has no general mechanisms for retaining molybdenum. It can pass through the soil and enter the groundwater. It is precipitated at high pH by calcium, and at low pH by iron and aluminum (Leeper, 1978). Molybdenum has a great affinity for iron oxide particles. Maximum sorption of molybdenum is at pH 4.2. Availability increases with pH. Keeping the pH near neutral does not limit availability. Phosphorus can replace molybdenum on oxide particles (EPA, 1976).

2.2.3.j SELENIUM

Selenium is essential for some animals. A narrow range exists between deficiency and toxicity in animals--0.5 to 4 ppm. Selenium can counteract mercury toxicity in some animals. There is little evidence that selenium is essential to plants, but it is taken up by plants (EPA, 1976).

In the soil selenium is least soluble at low pH. Under neutral to alkaline conditions it exists as the selenate anion which is quite soluble and does not sorb onto clay particles. Cappon (1984) found that sludge and compost were less effective in maintaining selenium buildup in the soil. Selenium volatilization from the soil may be enhanced by sludge or compost. More information is needed to evaluate the potential hazard from selenium in sludge (EPA, 1976).

2.2.3.k BORON

Boron is essential for plant growth. There is a very narrow margin between soil levels of boron that produce deficiency symptoms and that cause toxicity in plants. Deficiency symptoms occur at 0.04 mg/l water soluble boron. Toxicity occurs at soil solution concentrations above 1.0 mg/l (EPA, 1983).

In wastewater boron exists mainly in the form of the undissociated boric acid molecule. Being uncharged, it passes through the soil more readily than other elements. In humid and semi-humid regions, rainfall is usually sufficient to leach applied boron from the root zone (EPA, 1983).

2.2.4 Environmental Pathways

The EPA, in developing its regulations on sludge disposal, created a list of chemicals selected for environmental profile development. These chemicals then underwent further risk assessment to rate the hazards that they present in sludge (Lomnitz et al., 1985).

The EPA also identified the pathways by which these chemicals would influence the environment during sludge disposal. The metals and pathways identified for land application and landfilling of sludge are listed in Table 8 (Lomnitz et al., 1985).

2.3 REGULATIONS

Land application of sludge is regulated by the federal government and by most state governments. The EPA has limited regulations on land application and defers to state regulations in most matters. Many states have incorporated EPA regulations and guidelines into their regulations.

There are two types of regulations. Some regulations control the disposal process. They specify how the land application process is to be managed and/or set limitations based on characteristics of the disposal site. The force of these regulations is typically on the operator of the land application site. Other regulations control the sludge to be utilized in the

TABLE 8 METALS AND ENVIRONMENTAL PATHWAYS STUDIED FOR
DEVELOPMENT OF REGULATIONS

LAND APPLICATION OR DISTRIBUTION OF SLUDGE PRODUCTS

SOIL BIOTA TOXICITY:

Copper

TOXICITY TO SOIL BIOTA PREDATORS:

Cadmium, Zinc, Lead

PHYTOTOXICITY:

Cadmium, Chromium, Copper, Nickel, Lead, Zinc, Selenium

ANIMAL TOXICITY FROM PLANT CONSUMPTION:

Zinc, Molybdenum, Selenium, Copper, Cadmium, Iron

HUMAN TOXICITY FROM PLANT CONSUMPTION:

Cadmium, Zinc, Nickel, Lead, Selenium, Arsenic, Iron, Mercury

HUMAN TOXICITY FROM ANIMAL PRODUCTS:

Selenium, Zinc, Mercury, Cadmium

HUMAN TOXICITY FROM INCIDENTAL INGESTION:

Arsenic, Lead, Mercury, Cadmium, Iron

LANDFILLING OF SLUDGE

HUMAN CONSUMPTION OF CONTAMINATED GROUNDWATER:

Arsenic, Lead, Copper, Mercury, Nickel

Source: Lomnitz et al. (1985)

land application process. They limit the land application process according to the sludge characteristics. The force of these regulations is typically on the operator of the treatment facility or the distributor of the sludge product. In many states these regulations provide little or no regulatory control once the sludge has been distributed to the end user.

Currently, the only metal regulated by the EPA is cadmium. Cadmium loadings are subject to both annual and cumulative restrictions. The maximum annual loading is 0.5 kg Cd/ha. The maximum cumulative loading varies from 5 to 20 kg Cd/ha with the pH and cation exchange capacity (CEC) of the soil. These cumulative loading restrictions are given in Table 9.

EPA regulations also contain a second approach to cadmium control. Unlimited application of cadmium is allowed providing that four specific control measures are taken. First, the crop grown can only be used for animal feed. Second, the pH of the soil must be maintained at 6.5 or above as long as the food chain crops are grown. Third, a facility operating plan must describe how the animal feed will be distributed to prevent human ingestion. The plan must describe measures that will be taken to prevent cadmium from entering the human food chain due to alternative future land uses of the site. Fourth, future owners are provided notice (through provision in land record or property deed) that there are high levels of cadmium in the soil and food chain crops should not be grown (EPA, 1979a).

TABLE 9 MAXIMUM CUMULATIVE METAL LOADINGS ON LAND

Metal	Soil Cation Exchange Capacity (meq/100g)		
	0-5	5-15	>15
Maximum Cumulative Loading (kg/ha)			
Cd (1)	5	10	20
Cu (2)	125	250	500
Pb (2)	500	1000	2000
Ni (2)	125	250	500
Zn (2)	250	500	1000

-
- (1) EPA regulation
 (2) EPA guideline

In addition to regulating cadmium, the EPA has also issued guidelines on the maximum cumulative loadings for lead, zinc, copper and nickel. The maximum loadings vary with the CEC of the soil. Table 9 lists these guidelines.

The impact of heavy metals in municipal sludge on land application programs will vary from state to state depending on each state's regulations. States differ in the extent of regulation, what aspects of the sludge disposal process are regulated as well as the actual standards that are set.

States' regulations vary in the number of standards and requirements that are explicit. For example, some states limit the cumulative metals loadings of the soil, others set maximum permissible sludge metals concentrations and some states use both standards. States' regulations can also vary in the number of land disposal options that are explicitly regulated. Some states regulations refer only to land application in general, while others have separate standards for such options as agricultural use, land reclamation, roadside use, composting and distribution.

Most states require that each sludge application site be approved by the regulating agency. A typical site application contains a physical description of the proposed site and explains how the land application program will be managed. In some states the site application documents the compliance of the design with the regulations. In other states where there are fewer explicit

requirements, the regulating agency considers each site application on a case by case basis.

States' regulations can also differ with respect to other aspects of land applications and heavy metals. Some states issue regulations, some issue guidelines and some use both. The required interval between required sludge analyses can vary from state to state. The number of metals that are regulated also varies from state to state.

Appendix A contains a summary of state regulations of land application of sludge with respect to heavy metals for a number of states in the Northeast. In addition, Metcalf and Eddy (1986) has summarized the regulatory requirements for sludge compost marketing and distribution in the U.S.

2.4 MANAGEMENT OPTIONS

Management options to deal with metals in sludge can be divided into three categories. Pretreatment prevents the entry of the metals into the sewage treatment system. Additional treatment of the wastewater or sludge removes the metals from the sludge to be disposed of on the land. Land disposal options may be selected based on the metals levels in the sludge.

2.4.1 Pretreatment

The EPA requires wastewater treatment plants to implement an industrial pretreatment program to control entry of potentially

harmful wastes into the system (Koch et al., 1982). Zenz et al. (1975) and Lue-Hing et al. (1978) examined the effect of the pretreatment program of the Metropolitan Sanitary District of Greater Chicago on the sludge cadmium content. Zenz et al. found that enforcing an industrial discharge standard of 2.0 mg/l cadmium reduced sludge cadmium levels by as much as 72%. In spite of this, sludge cadmium levels were still well in excess of 25 ppm. Lue-Hing et al. concluded that further reductions in the discharge standard would cause only minimal improvement in reducing cadmium loadings to the wastewater treatment plants.

Koch et al. (1982) estimated the impact of a pretreatment program on the heavy metals content of sludge in two regional wastewater treatment districts in New Jersey. They concluded that in one district a 70% reduction in cadmium levels of the sludge was achievable. However, this would only result in a 10% increase in the amount of sludge that could be land applied because copper would then become the limiting element. They concluded that in some areas pretreatment would provide only minor benefits to land application programs.

Pretreatment programs can reduce both zinc and cadmium levels. The net effect can be a reduction, no effect or an increase in Zn/Cd ratios. This may not benefit land application in states that regulate the Zn/Cd ratios of sludge (84).

Brown (1985) notes that when a water supply system is responsible for significant metal loadings to a POTW, treatment

practices can be instituted to control the problem. The major obstacle is usually achieving interagency cooperation between the governing bodies of the water supply and wastewater treatment systems to deal with the problem.

2.4.2 Additional Treatment

Additional treatment to remove metals from wastewater or sludge is not commonly practiced. A number of studies investigating various treatment processes have been published. Most are laboratory or pilot studies. Few have been implemented on a large scale. Recovery of metals from sludge is not economical at this time (Eckenfelder and Santhanam, 1981).

The most commonly investigated treatment process is acid extraction of metals from sludge. The sludge is acidified to a pH between 1.5 and 3.0 to solubilize the metals. Contact times studied vary from 15 minutes (Scott and Horlings, 1975) to 24 hours (Wozniak and Huang, 1982). Metal removal is dependent upon the pH attained, the metal being removed, percent solids of the sludge and contact time (Wozniak and Huang, 1982).

Additional treatment is required to precipitate and remove the metals from the acid extract. Also, the pH of the original sludge must be returned to a level near neutral (Jenkins et al., 1981). Acid extraction approximately doubles the cost of sludge treatment and disposal (11).

Tyagi and Couillard (1987) investigated bacterial leaching of metals from anaerobically digested sludge using Thiobacillus

ferrooxidans and Thiobacillus thiooxidans. The bacterial leaching occurred at approximately pH 3.0. They found that these cultures solubilized 50% of the cadmium, 55% of the lead, 75% of the copper, and 95% of the zinc in the digested sludge.

Jenkins et al. (1981) compared acid treatment of sludge with extraction using EDTA. Results of the EDTA treatment varied for primary, waste activated and digested sludges. The EDTA treatment was more effective removing cadmium, copper and lead and less efficient for iron, chromium, nickel and zinc. The EDTA treatment is also much more expensive than acid treatment. They concluded that acid treatment of digested sludges was the better choice for metal removal.

Alibhai et al. (1985) examined EDTA treatment of sludge. They concluded that treatment with EDTA can:

1. extract metals from sludge generating more sites for adsorption.
2. extract extracellular polymers and perhaps reduce the metal binding capacity of the sludge.
3. change the nature of the binding sites.
4. render the sludge inactive. Inactivation does not affect binding capacity.
5. reduce the alkalinity of the sludge.

At one time chlorine stabilization was commonly practiced as an alternative to anaerobic digestion. In this process chlorine gas is applied to the sludge in an enclosed tank. The chlorine

reacts with the water to form HCl, lowering the pH and solubilizing the metals in the sludge (Obrist, 1987, Sterritt and Lester, 1982). The results obtained are similar to those for acid treatment. The release of metals is a function of the final pH, the type of sludge and the species of metal present. The filtrate from the chlorine oxidation process also has increased phosphorus and COD (Olver et al., 1975, Sukenik et al., 1977).

Chlorination of sludge can have adverse effects on the sludge and the environment after disposal. Chlorine oxidation forms a large number of chlorinated hydrocarbons in the sludge. Chlorinated sludge has been shown to reduce the growth of plants compared with unchlorinated sludge (Kamlet, 1979). Sukenik et al. (1977) concluded that the benefits of chlorine oxidation come from the acid effects while the chlorine effects could be deleterious.

Farooq and Aklaque (1982) investigated ozone oxidation of sludge to remove metals. They found that ozone released metals from sludge with only a slight decrease in pH. The alkalinity and COD of the sludge were also lowered by the treatment.

Huang (1982) conducted pilot plant studies using coprecipitation with lime in an upflow expanded sand bed. Calcium carbonate and the metal precipitates were plated onto the sand grains. The sand grain increased in size and eventually formed large dry chemical pebbles a few millimeters in diameter that were easy to handle in the disposal process.

Optimum removal was at pH 10.0-10.5 at pH 10.5 COD was reduced 21%, suspended solids 38%, volatile suspended solids 43% and total P 64%.

Fronk et al. (1985) investigated centrifugal treatment of sludge. A continuous countercurrent bowl centrifuge was used to separate sludge into two fractions. The heavier fraction contained precipitated metals and heavy organics (including pesticides). The efficiency of removal varied with the source of the metal. Better removals were obtained for most metals using digested sludge. They concluded that the process may be cost effective for upgrading sludge for composting or land application.

Bloomfield and Pruden (1975) investigated the effects of anaerobic and aerobic digestion on metal solubilization. They found that aerobic digestion or anaerobic digestion followed by aerobic digestion increased the amount of metals that were leachable with water.

2.4.3 Land Disposal Options

Several land disposal options are available for sludge. Land application is the application of sludge to land to enhance plant growth. Landfilling is disposal of sludge in a sanitary landfill with an impervious liner and cover. Dedicated land disposal is burial of sludge in unconfined sites. Land reclamation is the application of sludge to restore severely disturbed land such as strip mining sites. Distribution is the distribution or sale of dewatered or dried sludge or sludge products such as compost.

While the impact of metals on each of these options will vary from state to state, based on individual state regulations, some general effects may be noted.

Land application is, typically, most heavily influenced by the metals content of the sludge. Some states' regulations distinguish between different land uses in land application. Land which is to be used for growing food chain crops is subject to more restrictions than other uses such as horticultural crops, forestry crops, recreational land or roadside development.

Dedicated land disposal and land application are less subject to impacts by the metals content of the sludge. Larger quantities of sludge and lower quality sludge typically may be used.

Landfilling, where allowed, is the least impacted disposal option. Sludge disposal in a landfill is usually unrestricted as long as the metals content does not classify it as a hazardous waste. This is typically not the case with municipal sludge. Landfills are often used to dispose of nonhazardous sludges that are too contaminated for other disposal options.

User oriented regulations promulgated to control land application of sludge are usually inadequate to control distribution of sludge products. Distribution of sludge products is usually controlled by product oriented regulations. Typically these regulations are as restrictive or more restrictive than those controlling land application.

For any land disposal option, the regulations for the different metals will not have the same impact on the suitability of the sludge for disposal. Typically only one or two metals in the sludge will control the disposal options. The other metals usually are not present in sufficient quantities relative to the regulated maximum levels to effect disposal.

Mercury is usually one of the more tightly regulated metals found in sludge. Mercury, however, is typically found in sludges at such low levels that it is rarely a limiting element in sludge disposal schemes.

CHAPTER III

EXPERIMENTAL METHODS AND MATERIALS

The experimental methods for this study were developed in three steps:

1. Selection of an operating composting facility to study,
2. design of a sampling protocol, and
3. development of techniques for sample analysis.

3.1 FACILITY DESCRIPTION

The Hoosac Water Quality District treatment plant is located in Williamstown, Massachusetts. It provides wastewater treatment for Williamstown, North Adams and part of Clarksburg. The design flow is 20440 m³ per day (5.4 MGD). The average daily flow is 21200 m³ per day (5.6 MGD).

The plant employs conventional activated sludge treatment. Primary and secondary sludge are co-settled in the sedimentation basins. The combined sludge is then conditioned with lime and dewatered.

The sludge is dewatered on vacuum filters. The plant is staffed five days per week for two shifts per day. The vacuum filters typically operate continuously while the plant is staffed.

The dewatered sludge is taken by truck from the vacuum filters to the composting area every thirty minutes. The composting area is on the grounds of the treatment plant. Wood chips are used as a bulking agent. The wood chips are added to the sludge in the truck, mixed and fed by a conveyor from the truck into the composting bins. The ratio of bulking agent to sludge is 2:1 by volume.

Figure 1 is a process diagram of the composting facility. Sludge is composted in aerated static piles in concrete bins. This is a batch process. Each bin is 21.4 meters long, 4.6 meters wide and 3.7 meters high. One end of each bin is open. The sludge and bulking agent mixture is fed from the truck into the bin from the top. In the floor of each bin are two channels covered with grates. These function as combination air plena and leachate drains. The leachate from the compost piles is recycled back to the plant.

It takes two to four days to fill a bin (approximately 460 cubic meters). There are eight bins. The bins are filled and emptied sequentially. As a new bin is needed, the oldest batch is removed. A front-end loader empties the bin via the open end. The residence time of a batch of compost is three to five weeks.

Mechanical blowers force air through the compost piles in the bins via the air plena. The blowers operate on a cyclic basis. A typical cycle is 15 minutes on and 15 minutes off. This procedure maintains sufficient aeration in the pile without cooling it to

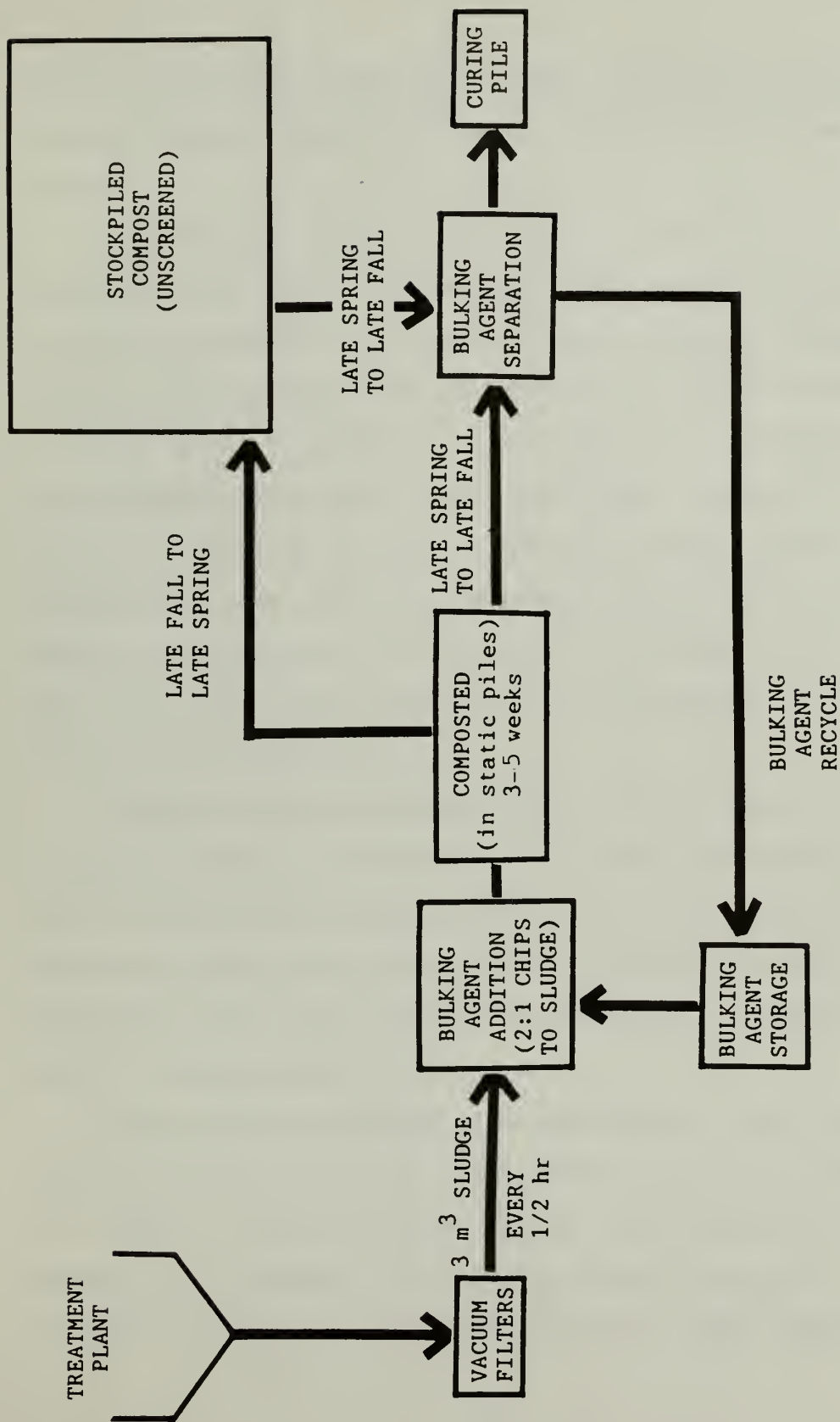


FIGURE 1 PROCESS DIAGRAM OF COMPOSTING FACILITY

below the thermophilic temperature range. Temperature probes inserted into the compost pile monitor the temperature in each batch.

In addition to the on-off cycling of the blowers, periodically the blowers are reversed. Each time the direction of air flow is reversed the air passes through different pathways in the pile. This increases the efficiency of the aeration process.

The method of handling the compost once it is removed from the bins differs depending on the time of year. During the warmer months the compost is screened to remove the bulking agent. A mechanical screener with a 0.5 inch mesh is used. The screened compost is then placed in a curing pile. It is kept in the curing pile for at least thirty days before it is disposed of. The wood chips are then recycled.

During the colder months evaporation from the compost piles is greatly reduced. Consequently, the compost produced from late fall to late spring is initially too wet to screen. During these months the compost plus bulking agent is stockpiled on site. Beginning in late spring the stockpiled material is screened and added to the curing pile.

The compost is classified under Massachusetts regulations as Type III material; subject to the strictest controls (see Appendix A). Because of the restrictions imposed, final disposal of the compost is in a landfill. The Type III classification is primarily due to high levels of cadmium from a single industrial

source (photochemical processing). This industry was required to install pretreatment by 31 March, 1988.

Because of the Type III classification, the plant does not sample its compost regularly. When a sample is collected, it is done by combining a number of randomly selected grab samples in a bucket. The contents are then mixed, and an aliquot of this material is removed for analysis.

3.2 SAMPLE COLLECTION

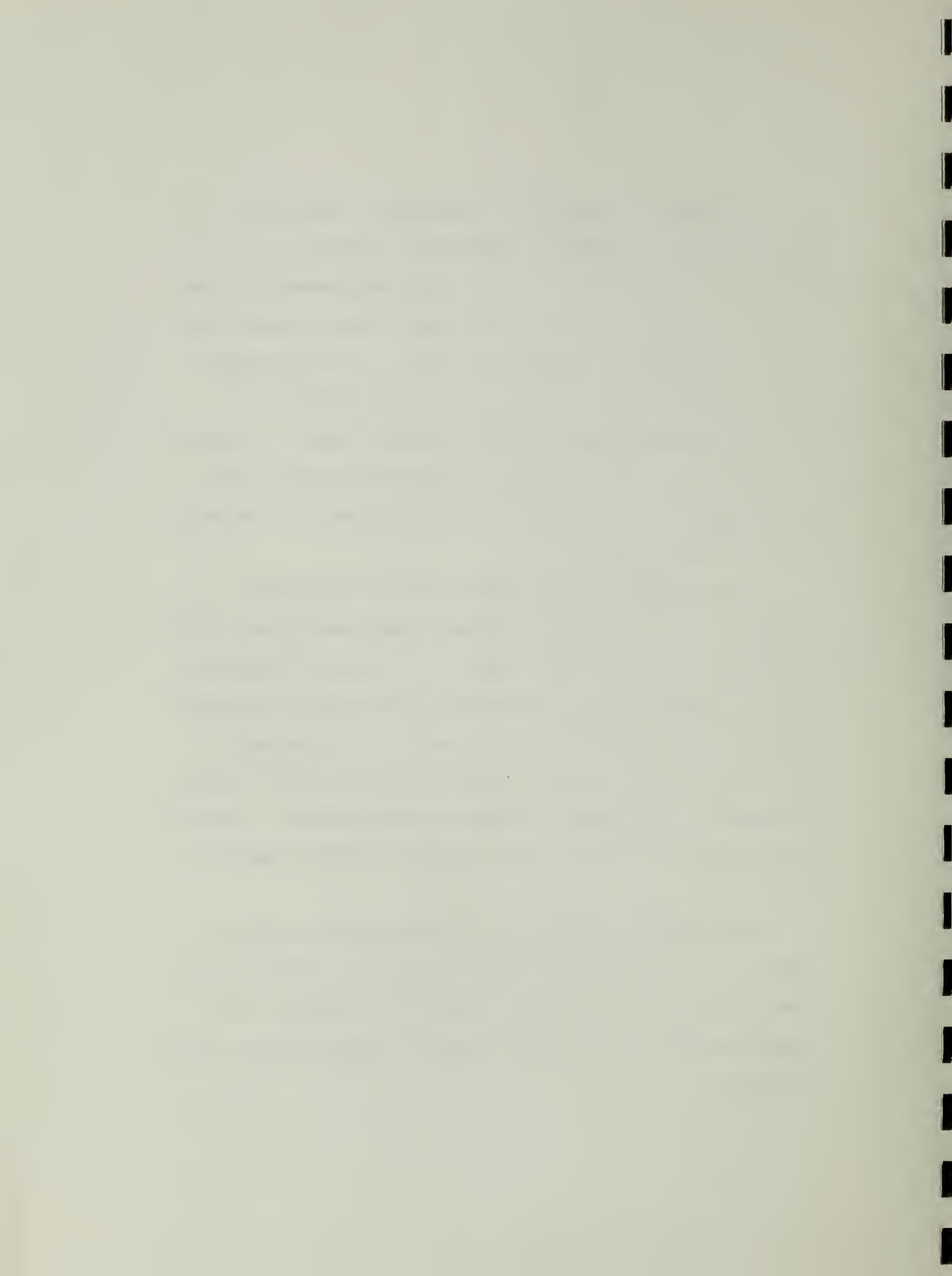
Three sampling procedures were designed for this study. Samples were collected from the sludge entering the composting process (sludge samples), the compost produced in each batch studied (batch compost samples) and the compost stored on site, either stockpiled or in the curing pile (stored compost samples).

Sampling programs for the sludge and the batch compost had similar objectives, but involved sampling from different types of populations. The objective of the sampling program for the sludge samples was to characterize the quality of each batch of sludge prior to composting. Sampling was from the continuous effluent solids stream of the treatment plant. This produced a time-based description of the sludge quality. The objective of the sampling program for the batch compost was to characterize the quality of the compost produced in each batch studied. Sampling from a batch of compost involved sampling from a population of independent concentrations at one point in time.

Two methods of sampling were considered. A systematic sampling program--sampling at predetermined spatial or temporal intervals--is technically easier to design and conduct since non-random bias does not have to be prevented. The non-random bias must be quantified when analyzing the data. A random sampling program produces unbiased data, but it is more difficult to produce a sampling program that is completely random. If there is no systematic variation in the study parameters, however, then random sampling and systematic sampling are practically equivalent (Ellis and Lacey, 1980).

It was assumed that there were no mid- or long-term systematic variations in the parameters under study (e.g., diurnal or weekly variations) in the sludge. It was assumed that there were no systematic spatial variations in the quality of the batch compost. To test for short term variations in sludge quality (within three hours or less), a number of samples were collected and analyzed. The results revealed no such variations. Based on this information, it was decided to employ systematic sampling procedures.

The objective of the sampling procedure for the stored compost was to simulate the sampling method used by the treatment plant personnel when sampling for regulatory compliance. No attempt was made to identify or eliminate sources of bias in this procedure.



Two primary criteria for the sampling procedures for sludge and batch compost were established. The first was that they were not unduly complex. These samples were to be collected by treatment plant personnel so a procedure was desired that would not be excessively time consuming. Also, a simple procedure was more likely to be applicable to other sites, making it useful for future studies. The second criterion was that the procedures be statistically justifiable. Proposed sampling methods were reviewed by a consultant from the University Statistical Consulting Center who pronounced them to be suitable.

Figure 2 is a diagram of the sampling program. Sampling was conducted on every other bin filled. These batches were termed study bins. Sampling of sludge and batch compost was conducted by treatment plant personnel. Sampling of stored compost was conducted by project participants.

Sludge samples were taken at the vacuum filters. Samples were collected only when a study bin was being filled and when the vacuum filters were operating. Samples were collected at two hour intervals only during the first shift of plant operation. The maximum number of samples collected in one day was four. Samples were collected in 120 ml containers and stored under refrigeration.

Batch compost samples were collected when a study bin was emptied. Four samples of the unscreened compost and bulking agent mixture were collected when the bin was half emptied and four were

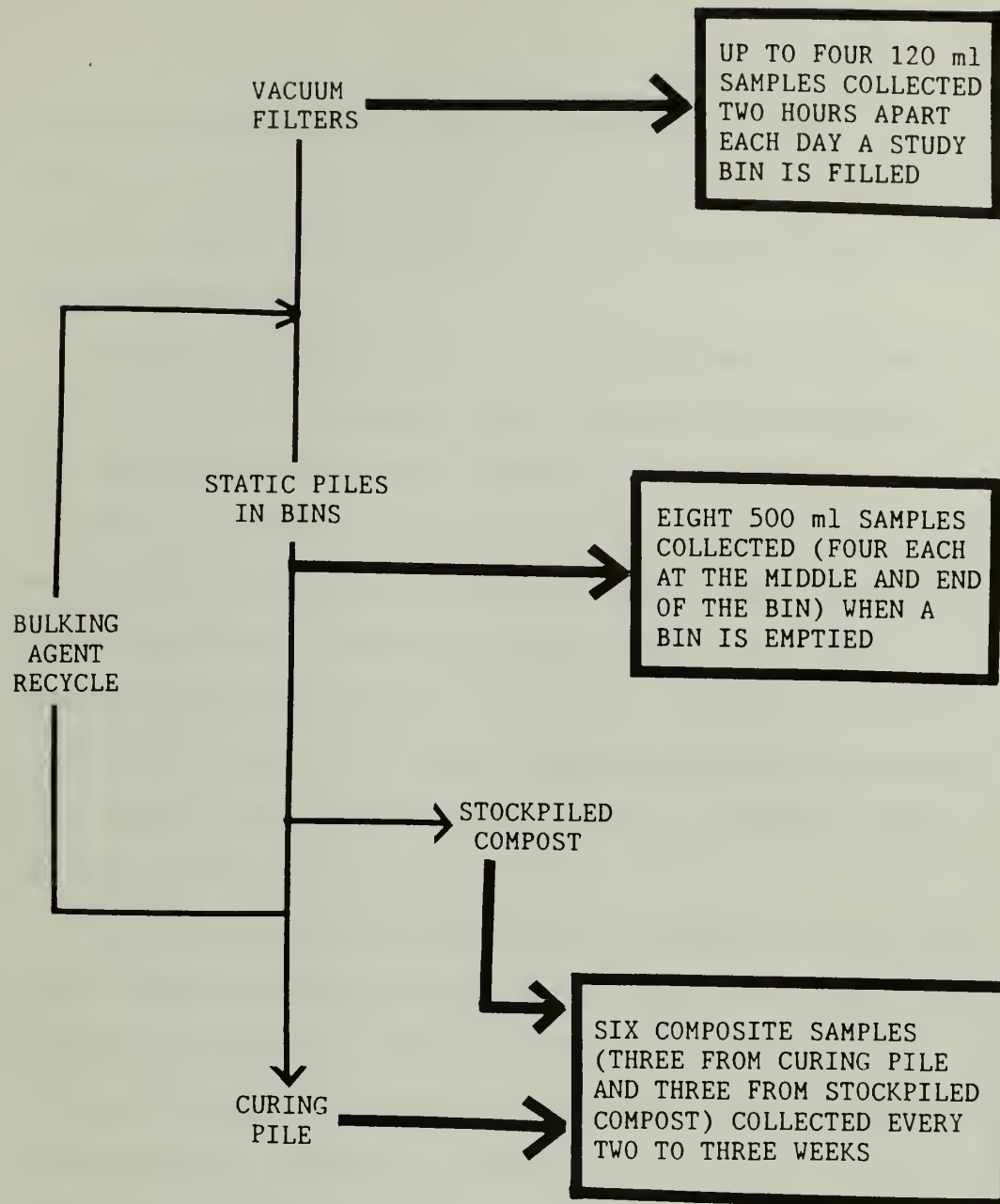


FIGURE 2 DIAGRAM OF SAMPLING PROGRAM



collected when the bin was nearly emptied. Each sample was collected at a random point on the cut face of the compost pile in the bin. Samples were collected in 500 ml containers and stored under refrigeration.

Samples of stored compost were collected when visits were made to the site to retrieve sludge and batch compost samples. This was typically done once every two to three weeks.

Three samples were collected from the curing pile per visit. Each sample was a composite of smaller samples taken at random points on the pile. The smaller samples were taken a few centimeters below the surface of the pile. Sampling points were approximately evenly distributed around the circumference of the pile. These samples were collected in 500 ml containers and immediately transported for processing.

Three samples were collected from the stockpiled compost per visit. Like the samples from the curing pile, these samples were composites of smaller samples taken at points distributed over the surface of the pile. Because the stockpile was much larger than the curing pile, sampling was conducted in two steps. First, samples were collected from the pile in three 13 liter buckets. The contents of each bucket were then thoroughly mixed and one 500 ml aliquot was taken from each bucket.

During the course of the investigation, one sample of leachate from a compost bin was collected. Also, one sample of

filtrate from the vacuum filters and one sample of settled sludge prior to lime addition were collected.

3.3 SAMPLE PROCESSING AND ANALYSIS

Sample processing consisted of two steps: sample preparation and digestion. Sample preparation was necessary to transform the raw sample as brought from the site, into a dried sample. The dried sample was a uniform and representative aliquot of the raw sample that was suitable for digestion. The dried sample was digested to destroy the solids and solubilize the solid and bound metals. The digest was then analyzed for the metals under study. Figure 3 is a flow chart of the steps used for sample processing and analysis.

Sludge was prepared by first taking an aliquot (approximately 40 ml) of the raw sample. This material was dried at 103°C overnight. The dried sludge was then ground with a mortar and pestle and redried at 103°C to produce a dried sample of sludge.

Samples of batch compost or stored compost contained significant portions of wood chips and wood chip fragments. The presence of a piece of wood in the sample to be digested would introduce a variable mass of inert material into the sample. This would result in an unquantifiable dilution of the heavy metals in the sample.

THE UNIVERSITY OF CHICAGO
DEPARTMENT OF THE HISTORY OF ARTS

ARTS AND CRAFTS

The Department of the History of Arts is a leading center for the study of the history of art and architecture. It is a department of the University of Chicago, and is one of the largest and most distinguished departments in the world. The department is headed by the Department Head, and is composed of several divisions, including the Division of Art History, the Division of Architecture, and the Division of Design. The department is also home to the University of Chicago Art Museum, which is one of the largest and most important art museums in the world. The department is committed to the highest standards of scholarship and to the advancement of the field of the history of art and architecture. It is a department that is proud of its long and distinguished history, and is committed to the future of the field.

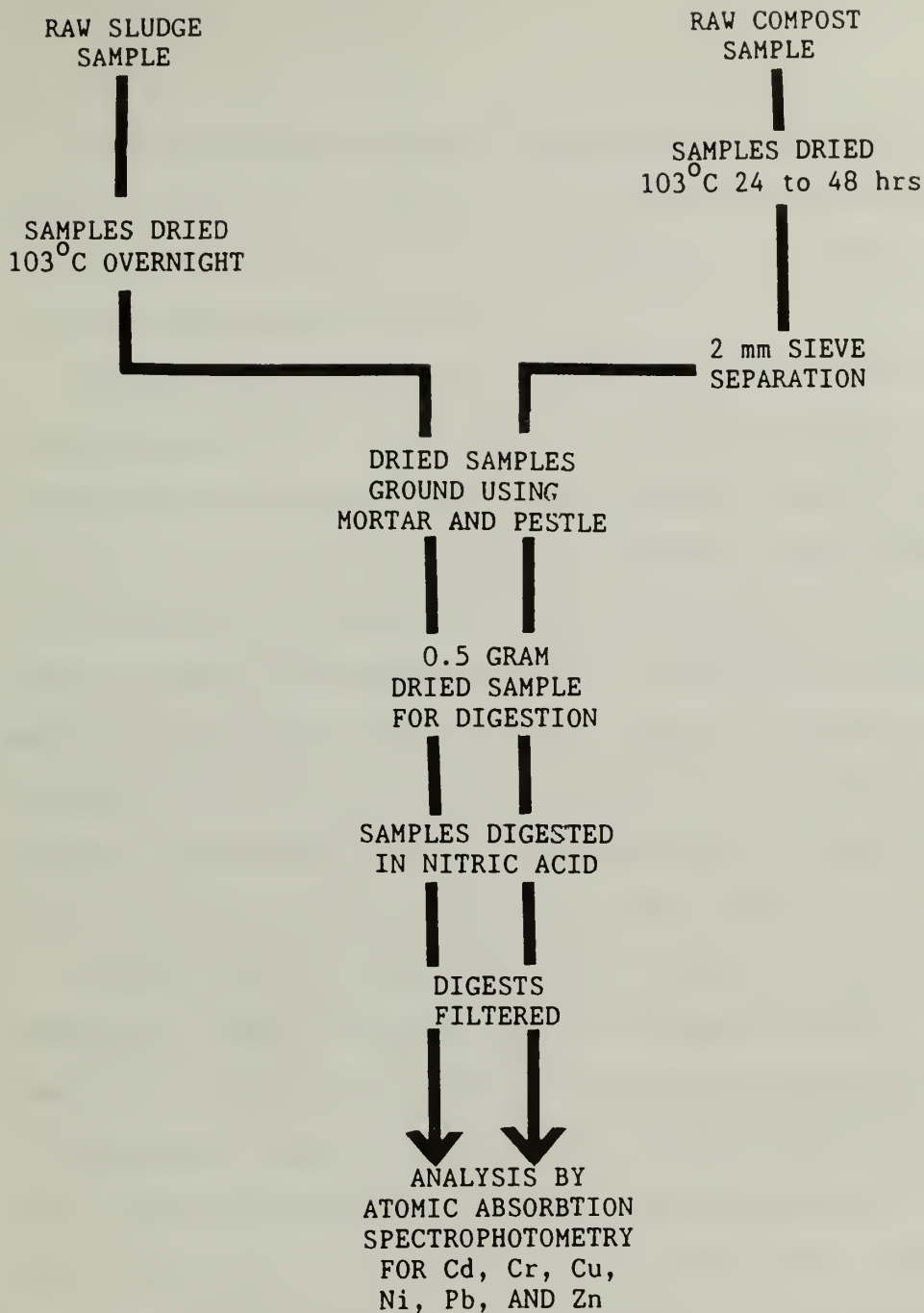


FIGURE 3 SAMPLE PROCESSING AND ANALYSIS FLOW DIAGRAM

To prevent this, a method of separation was needed that would remove the wood from the compost. No information was found in the literature describing such a method or defining the different fractions in this type of material.

The first step in devising a separation technique was to decide what portion of the wood should be removed. Removing all the wood would not be practical for two reasons. First, it would be difficult to identify and remove the smallest pieces of wood. These pieces are in the same size range as the particles of compost. Second, the composting process incorporates a certain amount of wood fragments into the final compost. The wood chips are physically and biologically degraded during composting and screening. The chips break into smaller pieces that cannot be recovered during the screening process (Haug 1980).

It was decided to sieve the compost to remove the wood. This technique is simple and easily applied to large numbers of samples. It also closely mimics the separation process employed at the treatment plant. Trial and error experimentation showed that a two millimeter sieve was ideal. It retained most of the larger wood chips yet passed almost all of the compost. Replicate metals analyses of processed samples yielded similar results.

A raw sample of batch compost or stored compost was dried at 103°C for 24 to 48 hours. The sample was placed on a two millimeter sieve with ten 0.5 inch porcelain balls. The sieve was placed on a sieve shaker and shaken for 12 to 15 minutes. The

porcelain balls dislodged the dried compost from the wood chips and broke up larger pieces of organic material allowing them to pass through the mesh.

The material remaining on the sieve--wood chips and larger bits of organic matter--was discarded. The material that passed the sieve still contained some larger fragments of wood. To remove these fragments the material was sieved two more times. Each time the sieve was shaken side-to-side gently by hand for about five seconds. The material that ultimately passed the sieve was considered to be just compost without any separable bulking agent.

The dried, sieved compost was then ground using a mortar and pestle. It was then redried at 103°C to produce a dried sample of compost.

Dried samples were digested in nitric acid using a method described by Thompson and Wagstaff (1980). The method was developed for use in analyzing large numbers of samples. Because of the large number of samples collected in this study, replicate digestions were not performed.

Samples were digested in 25mm X 200mm screw top Pyrex culture tubes. These tubes were calibrated gravimetrically to 50 ml. A sample weighing 0.5 grams was placed in the tube, and three milliliters of deionized water and 6 ml of nitric acid (Baker Instra-analyzed, J.T. Baker Co.) were added. The tubes were then placed on an electric six-position Kehlidal heating unit and the

solutions were heated to boiling. The solutions were gently refluxed for twenty minutes to digest the samples.

The digests were cooled to room temperature. They were then diluted to 50 ml in the tubes, capped and shaken gently. After settling for at least two hours, the digests were filtered through Whatman GF/C glass fiber filters (1.2 micron effective pore size). They were then ready to be analyzed.

Digested samples were analyzed for the metals under study (cadmium, chromium, copper, nickel, lead and zinc) using atomic absorption spectrophotometry. Analyses were performed using a Perkin-Elmer Model 3030B Atomic Absorption Spectrophotometer. The instrumental conditions for each metal analyzed are given in Appendix B, Table B1.

Mixed metal standards containing all six metals studied were used to standardize the spectrophotometer. The standards were prepared from commercially produced atomic absorption standards (Aldrich Chemical Company). The concentrations of each metal in the standards is given in Appendix B, Table B2. A blank solution was prepared using deionized water. The blank solution and all the standards were ten percent nitric acid by volume to match the matrix of the digests as closely as possible.

Digests were diluted 10:1 when analyzing for zinc. This was done so the sample concentrations would be within the linear range of the instrument. The diluted digests were also acidified to ten percent nitric acid by volume.

A large sample digest was prepared and used for quality control monitoring. The QC sample was analyzed each time a set of samples was analyzed to monitor any variability from session to session in the spectrophotometer. The values of the QC sample readings are given in Appendix B, Table B3.

Representative sludge samples were analyzed for total solids content. Representative compost samples were analyzed for volatile solids content. Both these analyses were performed according to Standard Methods (APHA, AWWA, and WPCF, 1985).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 BATCH COMPOSTING STUDIES

Sampling was conducted from January, 1988 through June, 1988. Thirteen batches of sludge, designated A through M, were sampled. Compost samples from batches D and E were lost. Complete data is available for eleven batches. Table 10 lists the beginning and ending dates of composting for each batch.

The results of the metals analyses of these samples are presented in Appendix C, Table C1. The results of the metals analyses of the sludge and batch compost for each batch were each reduced to an average concentration of each metal in each batch. These average concentrations are listed in Appendix C, Table C2. These values are also presented in Figures 4 through 9 (cadmium, chromium, copper, nickel, lead and zinc, respectively).

The cadmium concentrations in the sludge and batch compost declined during the first half of the study period. This is presumed to be due to the use of pretreatment by the industrial discharger lowering the cadmium concentration in the raw wastewater. Cadmium concentrations increased in the latter part of the study period. The reason for this is not known.

The average cadmium concentration in the sludge varied from

TABLE 10 BATCH COMPOSTING SCHEDULE

BATCH	DATE PILE CONSTRUCTED	DATE PILE REMOVED	DAYS COMPOSTED
A	01/25	03/01	37
B	02/01	03/03	31
C	02/11	03/15	33
F	03/10	04/13	34
G	03/25	04/27	33
H	04/04	05/09	35
I	04/13	05/18	35
J	04/25	05/25	30
K	05/05	06/08	34
L	05/16	06/21	36
M	05/24	06/29	31

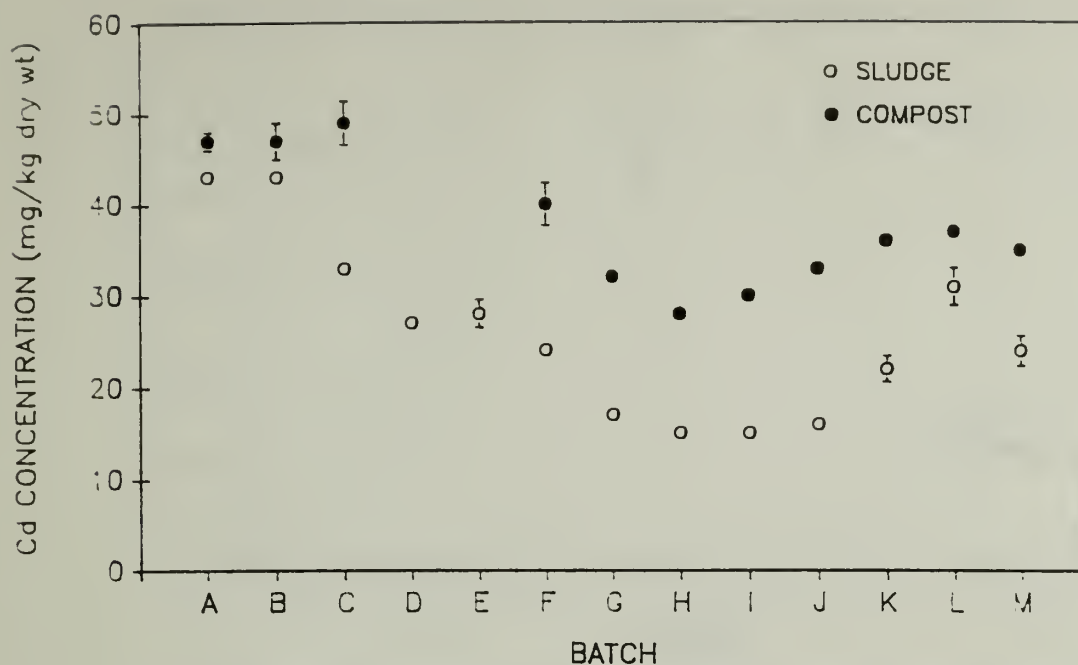


FIGURE 4 AVERAGE (\pm STD ERROR) CADMIUM CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES

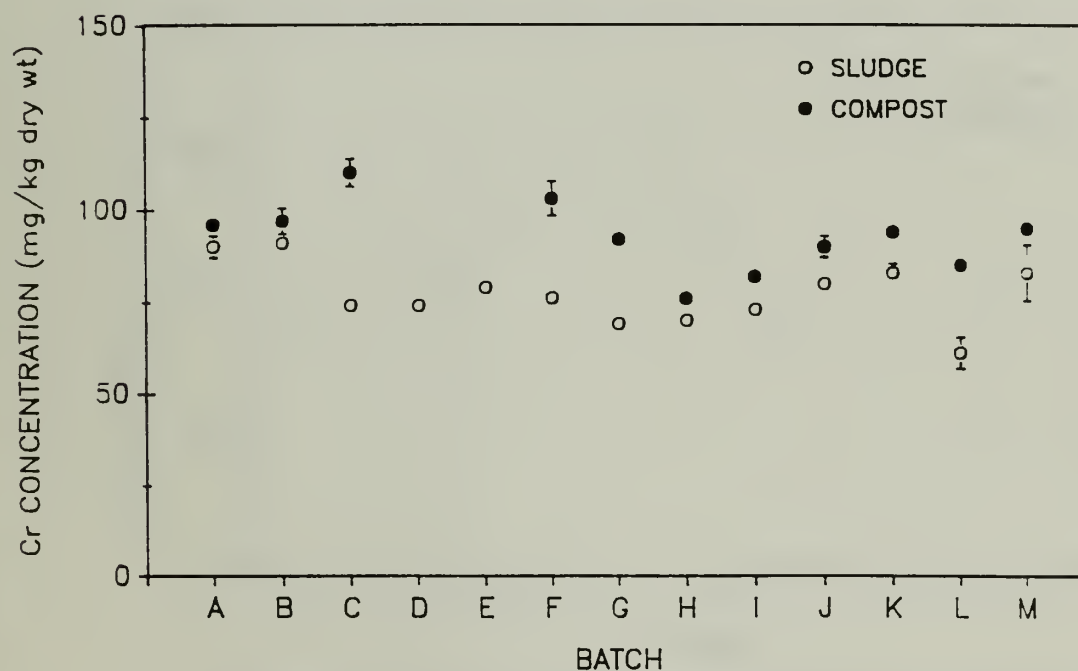


FIGURE 5 AVERAGE (\pm STD ERROR) CHROMIUM CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES

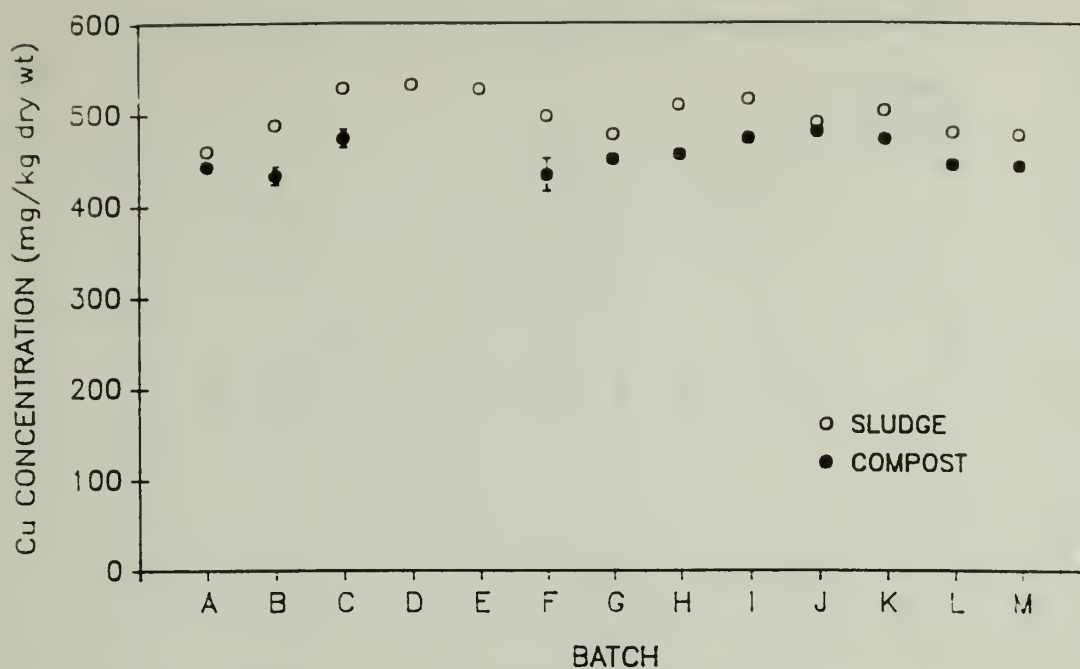


FIGURE 6 AVERAGE (\pm STD ERROR) COPPER CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES

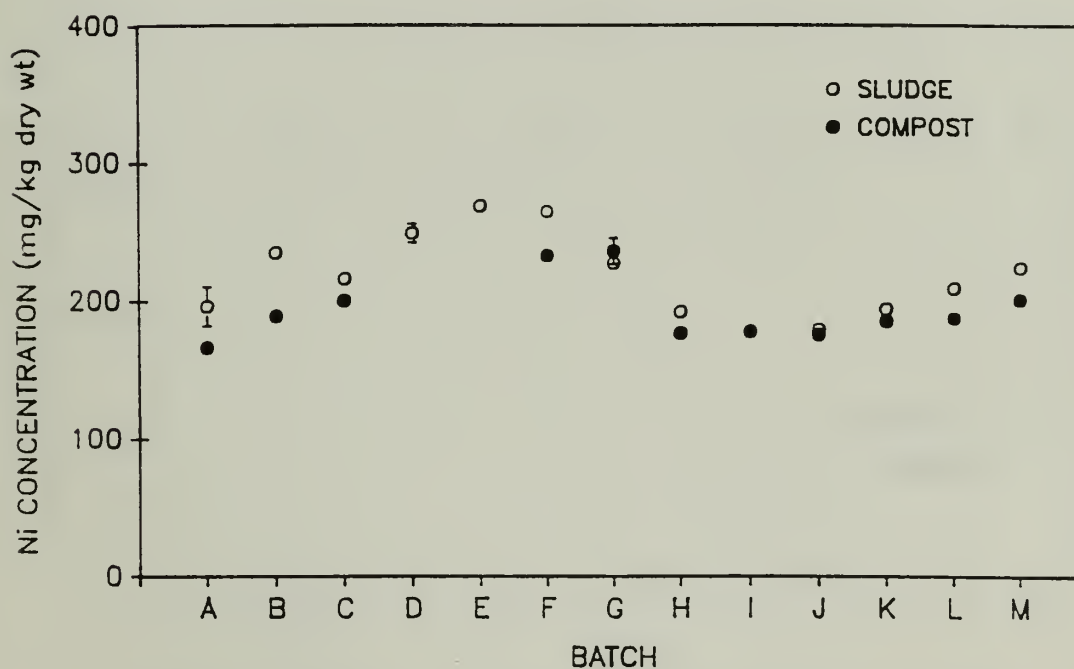


FIGURE 7 AVERAGE (\pm STD ERROR) NICKEL CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES

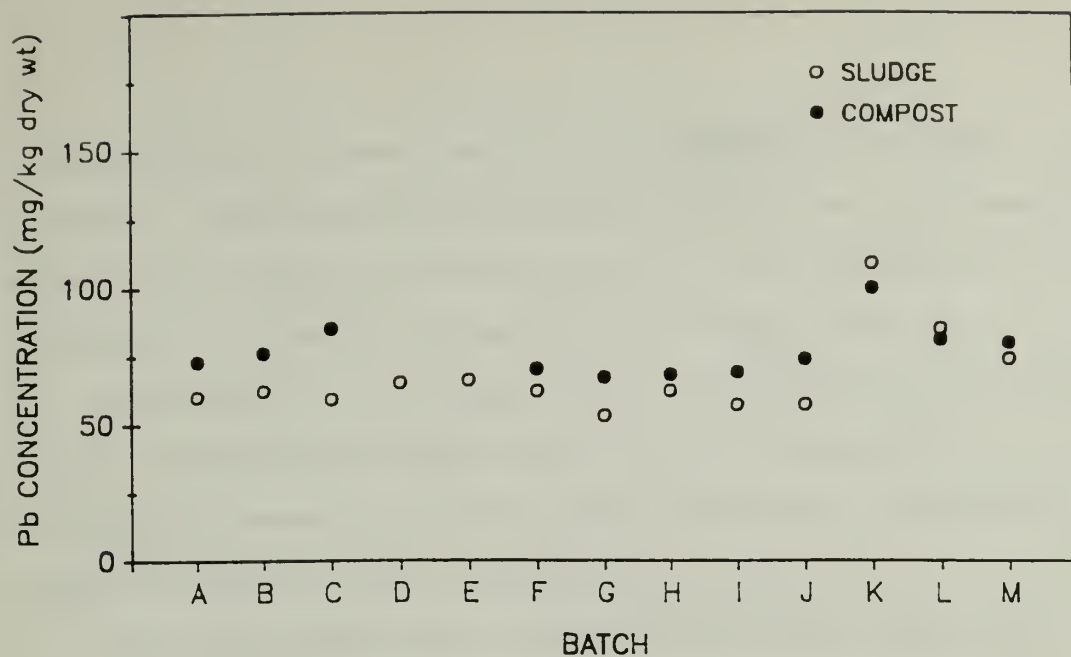


FIGURE 8 AVERAGE (\pm STD ERROR) LEAD CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES

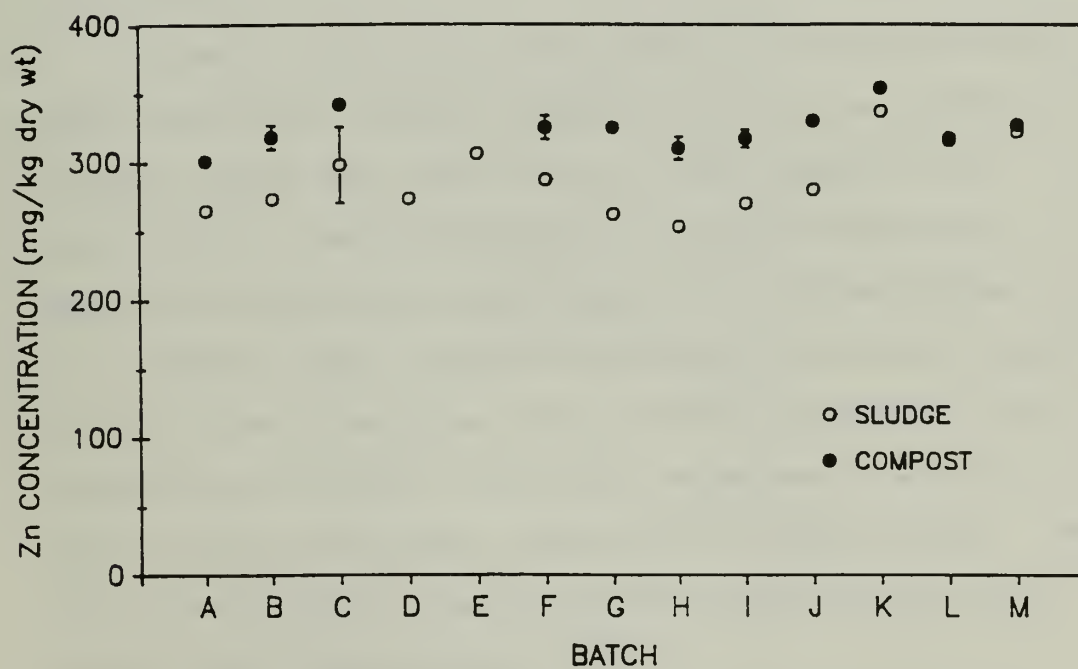


FIGURE 9 AVERAGE (\pm STD ERROR) ZINC CONCENTRATIONS IN SLUDGE AND BATCH COMPOST SAMPLES

1900
1901

1. The first part of the paper is devoted to a general discussion of the problem of the distribution of the elements of a finite group. It is shown that the distribution of the elements of a finite group is determined by the structure of the group and the structure of the field over which the group is defined. The second part of the paper is devoted to a detailed study of the distribution of the elements of a finite group of prime order. It is shown that the distribution of the elements of a finite group of prime order is determined by the structure of the group and the structure of the field over which the group is defined.

2. The second part of the paper is devoted to a detailed study of the distribution of the elements of a finite group of prime order. It is shown that the distribution of the elements of a finite group of prime order is determined by the structure of the group and the structure of the field over which the group is defined. The third part of the paper is devoted to a detailed study of the distribution of the elements of a finite group of prime order. It is shown that the distribution of the elements of a finite group of prime order is determined by the structure of the group and the structure of the field over which the group is defined.

3. The third part of the paper is devoted to a detailed study of the distribution of the elements of a finite group of prime order. It is shown that the distribution of the elements of a finite group of prime order is determined by the structure of the group and the structure of the field over which the group is defined. The fourth part of the paper is devoted to a detailed study of the distribution of the elements of a finite group of prime order. It is shown that the distribution of the elements of a finite group of prime order is determined by the structure of the group and the structure of the field over which the group is defined.

43 mg/kg (Type III classification, see Appendix A) to 15 mg/kg (Type II). The average cadmium concentration in the batch compost varied from 49 mg/kg to 30 mg/kg (Type III). The average nickel concentration in the sludge varied from 269 mg/kg (Type III) to 177 mg/kg (Type I). The average nickel concentration in the batch compost varied from 236 mg/kg (Type III) to 175 mg/kg (Type I). The average concentrations of the other four metals studied were within the limits of Type I material at all times.

The average total solids content of the sludge varied from 14.61 to 17.48 percent during the study period. The average volatile solids content of the batch compost varied from 38.81 to 43.16 percent.

In general, the metals concentrations in the sludge changed during composting. Cadmium, chromium and zinc concentrations in the batch compost were greater than or equal to those in the parent sludge. Lead concentrations in the batch compost were higher than those in the parent sludge in all but two batches in which they were lower. Copper concentrations in the batch compost were lower than in the parent sludge for for all batches. The concentrations of nickel in the batch compost were less than or equal to those in the parent sludge in ten of eleven batches. The batch to batch changes in metals concentrations followed similar trends in both sludge and batch compost.

The percent increase in metals concentrations during composting for each batch is presented in Figure 10. A positive

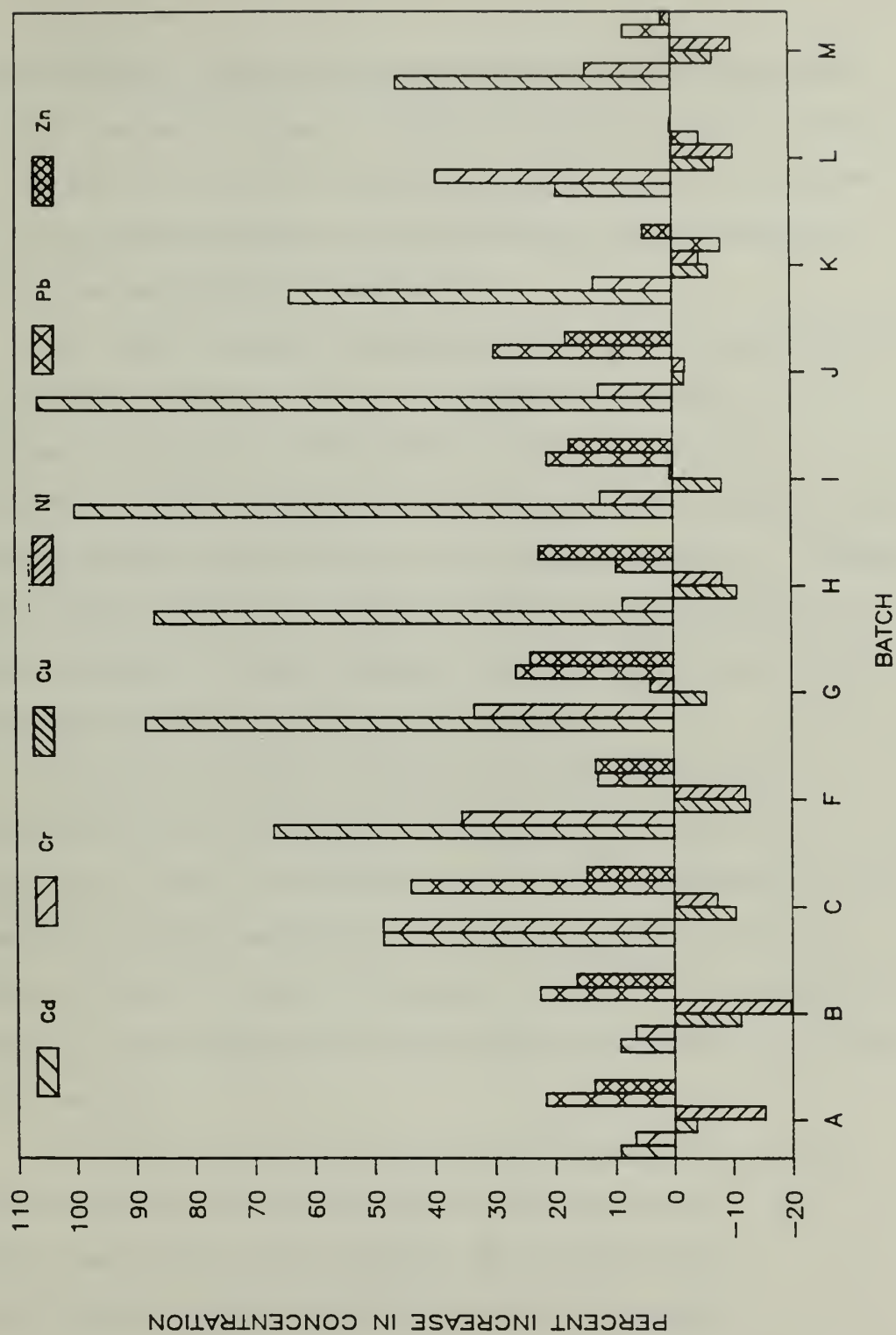


FIGURE 10 PERCENT INCREASE (+) OR DECREASE (-) IN SLUDGE METALS CONCENTRATIONS DURING COMPOSTING

change denotes a higher metal concentration in the batch compost than in the parent sludge. A negative change indicates a decrease in the metal concentration during composting. Table 11 contains the mean and median values of the calculated percent changes in metals concentrations for each metal.

The change in metals concentration during composting differed for different metals. The percent increase in cadmium concentration increased from batch C to batch J and then decreased. This is opposite of the batch to batch changes in the actual cadmium concentrations in the sludge and compost. Although the percent increase in cadmium concentration was increasing in these batches, the actual change in concentration between sludge and compost only varied from 13 to 17 mg/kg.

The percent change in chromium concentrations during composting decreased from batch C through batch J and then increased. This is the opposite of the effect for cadmium. The magnitude of the change was less than for cadmium. It is not known if these two trends are related. There were no discernable patterns in the magnitudes of the change in concentrations of the other metals.

The percent increase of the cadmium concentration during composting was much greater than for the other metals. This effect may be due to the chemistry of the sludge-metal interactions. Another reason may be that the cadmium concentration in the sludge was much lower than the other metals,

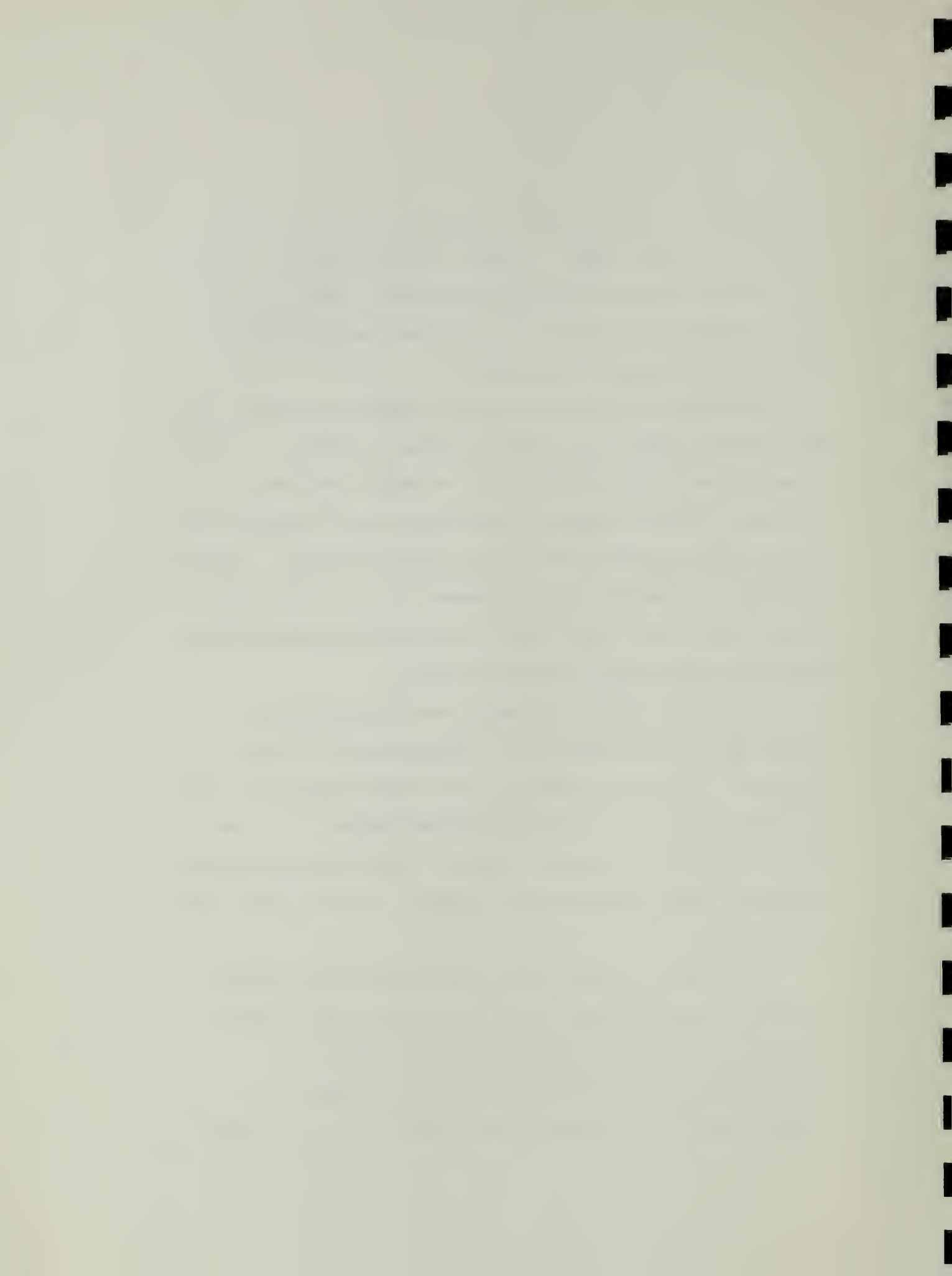


TABLE 11 MEAN AND MEDIAN VALUES OF PERCENT CHANGE IN
SLUDGE METALS CONCENTRATIONS DURING COMPOSTING

<u>METAL</u>	<u>MEAN</u>	<u>MEDIAN</u>
Cd	58.5	63.6
Cr	21.0	13.3
Cu	-7.8	-7.3
Ni	-7.8	-8.3
Pb	16.7	21.1
Zn	13.3	14.8

making it more sensitive to changes measured on a percentage basis. The percent increase in the cadmium concentrations were five to ten times that of zinc, while the concentrations of zinc in the sludge were 10 to 20 times the concentrations of cadmium.

The systematic increase in concentration of some metals during composting while other metals decreased in concentration indicates that the change in metals concentrations is not due solely to gain or loss of total solids. There must be an actual loss of metals occurring from the compost piles. Several mechanisms of metals losses are possible. These are:

1. Methylation of the metals by microorganisms and loss by volatilization,
2. sorption of the metal onto the bulking agent and removal during screening, and
3. removal in the leachate from the compost pile.

No information was found in the literature to indicate that methylation occurs to any significant extent during composting. Sorption of metals onto the bulking agent was not investigated in this study. Analyses were conducted to determine if metals were removed via the leachate.

A sample of vacuum filtrate was collected from the sludge composted in batch A. A sample of leachate from batch H was collected. The results of the metals analyses of these liquid samples are presented in Table 12.

TABLE 12 RESULTS OF METALS ANALYSES OF LIQUID SAMPLES

BATCH	SAMPLE TYPE	METALS CONCENTRATION (mg/L)					
		Cd	Cr	Cu	Ni	Pb	Zn
A	Filtrate	0.01	nd	0.42	0.16	nd	0.05
H	Leachate	0.01	nd	0.17	0.40	nd	0.13

nd- not detected

Both the filtrate and leachate samples contained copper and nickel. Concentrations of these metals decreased during composting of batch A and batch H. Both samples also contained cadmium and zinc. The concentrations of these metals increased during composting in batch A and batch H.

The concentrations of cadmium and zinc in the liquid samples were lower than those of copper and nickel. If the cadmium and zinc were being lost from the compost pile, the loss was probably small enough to be offset by the increase in concentration due to the degradation of total solids during composting. This would result in a net increase in the concentrations of these metals.

The metals in the liquid samples may be from the loss of metals during composting, or they may be due to metals that remain in the liquid portion throughout the treatment process. These metals may enter the liquid portion of the solid stream at several points in the treatment process:

1. In the activated sludge process
2. during sludge conditioning, and
3. during composting.

In the aeration basin, metals in solution are adsorbed onto sludge solids. The efficiency of this process is 30-98 percent, varying with the individual metal and the treatment plant. Some of the metals that remain in solution will be carried over into the solid stream in the pore water of the sludge. These metals could then be detected in the vacuum filtrate. If this was the

THE UNIVERSITY OF CHICAGO

DEPARTMENT OF THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

only source of metals in the filtrate, then the concentrations would be the same as or lower than the metals in the plant's treated effluent. The addition of lime during conditioning would precipitate some of the metals, lowering the concentrations.

A sample of final effluent was not collected. The concentrations of the metals in the filtrate were compared to the metals concentrations in secondary effluents obtained from the literature and listed in Table 1. The concentrations of cadmium and zinc were within the ranges of values reported. The concentrations of copper and nickel were much higher than those reported.

Metals could enter the liquid fraction of the solid stream during sludge conditioning. As noted in chapter two, it is possible for metals to be displaced from the sludge by the addition of other cations. The sludge at this facility is conditioned with lime (Ca(OH)_2). If the added calcium ions displaced metal ions from the sludge they would be those metals with the lower affinities for the sludge. Cheng et al. (1975) and Sterritt and Lester (1981b) reported that the order of affinity of metals for sludge is $\text{Cr} > \text{Cd} > \text{Ag} > \text{Pb} > \text{Zn} > \text{Cu} > \text{Ni}$, with some variation with pH. In the filtrate sample, copper and nickel were present at higher concentrations than cadmium and zinc. Chromium and lead were not detected.

The pH of the leachate was 11.5. At this pH, those metals detected in solution would be primarily in the form of anionic hydroxide complexes.

To determine if metals are lost during conditioning, a sample of unconditioned sludge was collected for analysis. The sludge was mechanically dewatered to 11 percent solids without chemical conditioning and analyzed for the study metals. The results are presented in Table 13. Also presented in Table 13 are the ranges of metals concentrations measured in the conditioned sludge collected during the batch composting study.

The concentrations of copper and nickel are much higher than in the conditioned sludge. The concentration of cadmium was approximately the same as the concentrations measured in the conditioned sludge. The concentration of chromium was approximately the same as the lower concentrations measured in the conditioned sludge. The concentrations of lead and zinc were slightly higher than those measured in the conditioned sludge samples.

Differences in metals concentrations between conditioned and unconditioned sludge could be due to loss of metals during conditioning. Another factor is the dilution of the sludge total solids by the lime added during conditioning. This facility adds lime at the rate of 20 percent by weight. This would result in a corresponding dilution of sludge constituents by the calcium solids.

TABLE 13 RESULTS OF METALS ANALYSIS OF UNCONDITIONED SLUDGE

DATE	METALS CONCENTRATION (mg/kg dry wt)					
COLLECTED	Cd	Cr	Cu	Ni	Pb	Zn
06/21	31	24	716	340	92	437
Range measured in conditioned sludge	13-48	34-134	392-587	148-284	46-128	236-372

The concentrations of nickel and zinc were higher in the leachate than in the filtrate. It is not completely justifiable to compare these two samples because they were collected from different batches of sludge. This difference however, may indicate that a loss of metals occurs from the sludge solids during composting. As the organic solids are degraded during composting, metals may be released from the adsorption sites and enter the liquid phase of the sludge. These soluble metals would be susceptible to loss from the pile via leaching.

Another factor is the change in pH during composting. The pH of the leachate was 5.7. At this pH, previously precipitated metals in the sludge could be resolubilized.

If these were the only factors involved, then it would be expected that all the study metals would be detected in the liquid samples. Chromium and lead were not detected. The reason may be that as the metal ions are desorbed from the sludge some may re-adsorb displacing other ions on other adsorption sites. The net effect of this would be the loss of only those metals with lower affinities for the sludge.

4.2 STATISTICAL ANALYSIS

Statistical analysis of the data from the batch composting study was performed. The data was analyzed to determine if the differences in metals concentrations of the sludge and compost

samples were statistically significant. First, a "t"-test (Student's t-distribution) was used to compare the differences in metals concentrations of the sludge and batch compost using the average concentrations for each batch. The probability that the differences were significant exceeded 99 percent.

Next, Analysis of Variance (ANOVA) was performed using the results of the individual samples analyses. Three analyses were performed. The differences between the sludge and batch compost metals concentrations were compared for all samples collected. Next, the differences in the metals concentrations were analyzed for both sludge and batch compost. Finally, a two-way analysis was performed to compare the batch to batch variability with the variability between sludge and batch compost metals concentrations.

The specific hypotheses tested and the results of the analyses are presented in Table 14. For comparisons of metals concentrations between sludge and compost, and between batches the significance of F (the probability that the hypothesis tested is true) was less than 0.001 for each metal. For the two way analysis, the significance of F was less than 0.03 for each metal.

Based on the results of the statistical analysis the following may be concluded:

1. The measured changes in metals concentrations between sludge and batch compost are significant.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is essential for ensuring transparency and accountability in the organization's operations.

2. The second part outlines the specific procedures for recording and reporting these activities. It details the steps involved in data collection, analysis, and the preparation of reports for management review.

3. The third part addresses the role of the audit committee in overseeing the financial reporting process. It highlights the committee's responsibility for ensuring that the financial statements are fair, balanced, and free from material misstatements.

4. The fourth part discusses the importance of internal controls in preventing and detecting errors and fraud. It describes the various control mechanisms in place and the measures taken to ensure their effectiveness.

5. The fifth part provides a summary of the key findings and recommendations from the audit. It identifies areas of strength and areas for improvement, and offers practical suggestions for enhancing the organization's financial reporting and internal control systems.

TABLE 14 RESULTS OF ANALYSIS OF VARIANCE OF BATCH COMPOSTING DATA

SIGNIFICANCE OF F			
METAL	BATCH TO BATCH	SLUDGE VS COMPOST	COMBINED ANALYSIS
Cd	***	***	***
Cr	***	***	***
Cu	***	***	0.023
Ni	***	***	***
Pb	***	***	***
Zn	***	***	0.027

*** less than 0.001

HYPOTHESES TESTED:

- (1) The concentration of a metal measured in sludge samples in any batch are the same as those measured in compost samples for the same batch.
- (2) The concentration of a metal measured in sludge or compost samples in any batch are the same as those measured in samples in any other batch.
- (3) The ratio of the variation measured between sludge and compost samples to the variation measured between samples in different batches is less than or equal to the critical ratio (or the error mean square).

2. Metals concentrations measured in samples in any batch are significantly different and distinct from those measured in any other batch.
3. The effect of composting on sludge metals concentrations is significantly greater than the effect of those factors influencing batch to batch variations.

4.3 STORED COMPOST ANALYSES

Eighteen samples were collected from the curing pile on eight occasions. Fifteen samples of stockpiled compost were collected on five occasions. The volatile solids content of the stored compost samples were between 34 and 39 percent. The results of the metals analyses of these samples are presented in Appendix C, Table C3. Qualitative comparisons were made between the metals concentrations in the batch compost and the stored compost to illustrate the variations in compost quality that can exist on-site.

These results were reduced to average metals concentrations for each type of sample on each day they were collected. These average concentrations are listed in Appendix C, Table C4. These values are also presented with the average metals concentrations of the batch compost samples in Figures 11 through 16 (cadmium, chromium, copper, nickel, lead and zinc, respectively). The

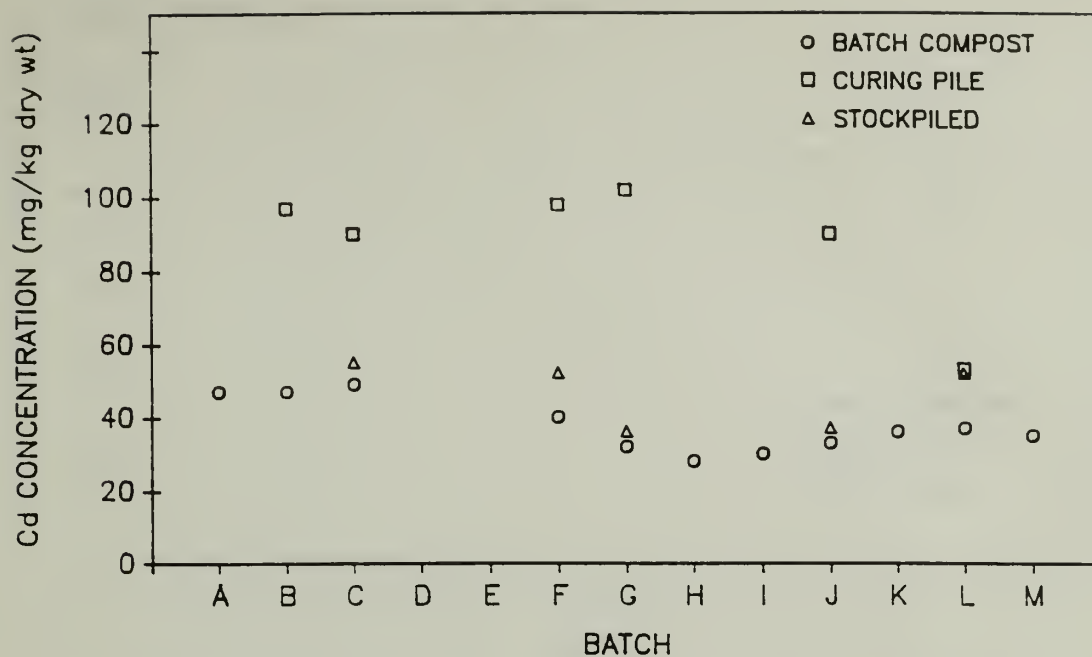


FIGURE 11 AVERAGE CADMIUM CONCENTRATIONS IN COMPOST SAMPLES

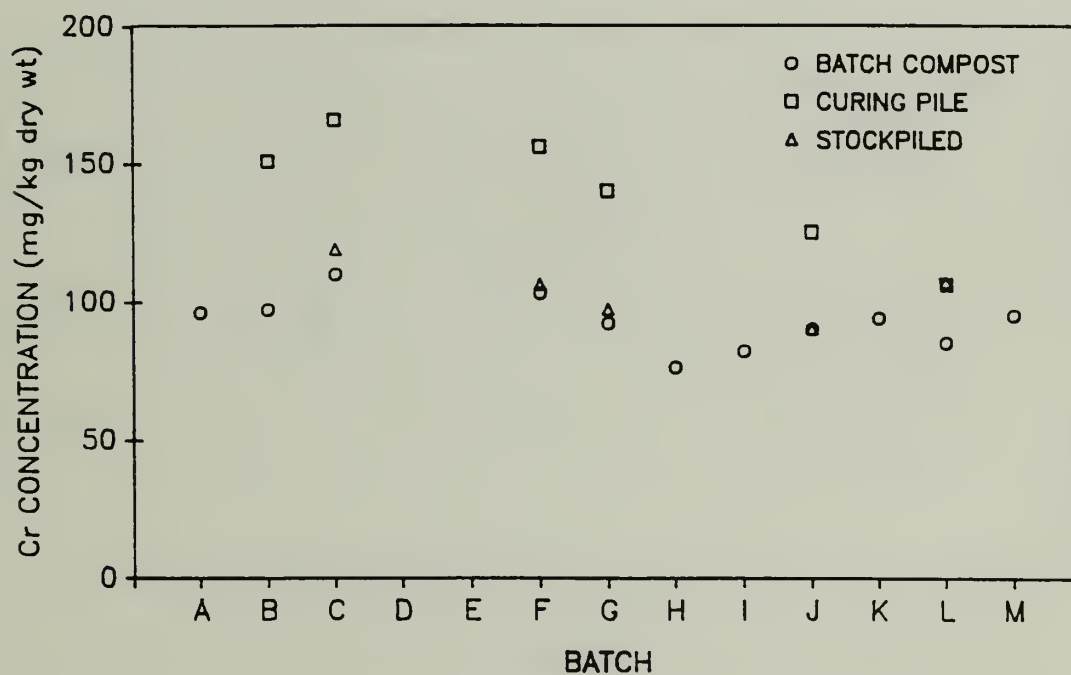


FIGURE 12 AVERAGE CHROMIUM CONCENTRATIONS IN COMPOST SAMPLES

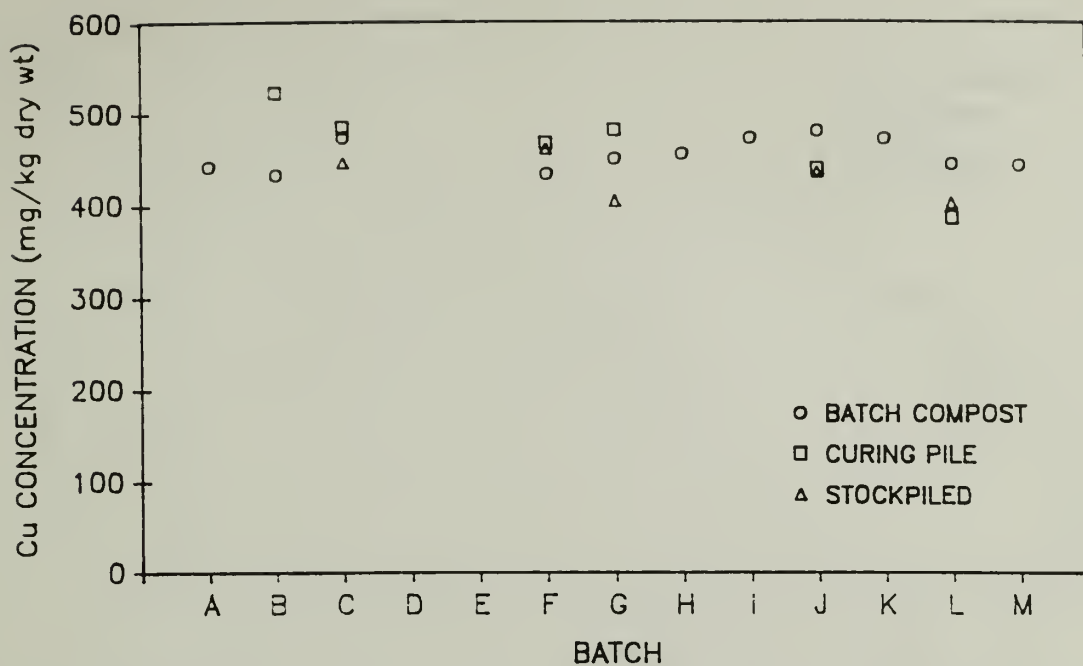


FIGURE 13 AVERAGE COPPER CONCENTRATIONS IN COMPOST SAMPLES

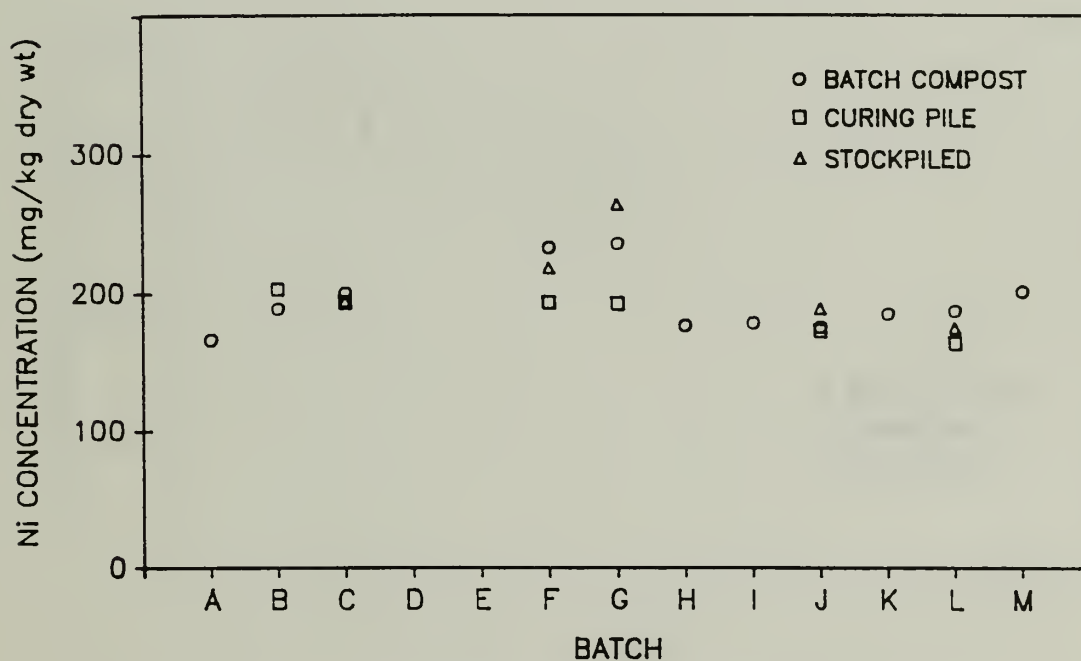


FIGURE 14 AVERAGE NICKEL CONCENTRATIONS IN COMPOST SAMPLES

THE
JOURNAL
OF
THE
ROYAL
ANTHROPOLOGICAL
INSTITUTE
OF GREAT BRITAIN
AND IRELAND
PART I
1901

CONTENTS
PAGES
The Evolution of Man, by Prof. Huxley, F.R.S. 1
The Evolution of Man, by Prof. Huxley, F.R.S. 2
The Evolution of Man, by Prof. Huxley, F.R.S. 3
The Evolution of Man, by Prof. Huxley, F.R.S. 4
The Evolution of Man, by Prof. Huxley, F.R.S. 5
The Evolution of Man, by Prof. Huxley, F.R.S. 6
The Evolution of Man, by Prof. Huxley, F.R.S. 7
The Evolution of Man, by Prof. Huxley, F.R.S. 8
The Evolution of Man, by Prof. Huxley, F.R.S. 9
The Evolution of Man, by Prof. Huxley, F.R.S. 10

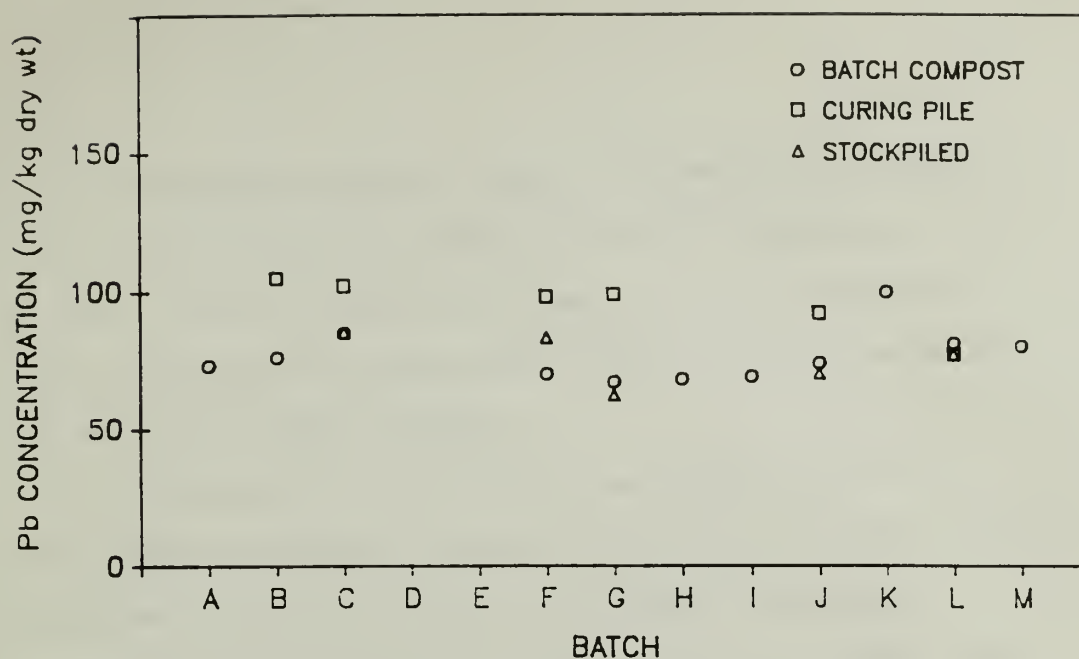


FIGURE 15 AVERAGE LEAD CONCENTRATIONS IN COMPOST SAMPLES

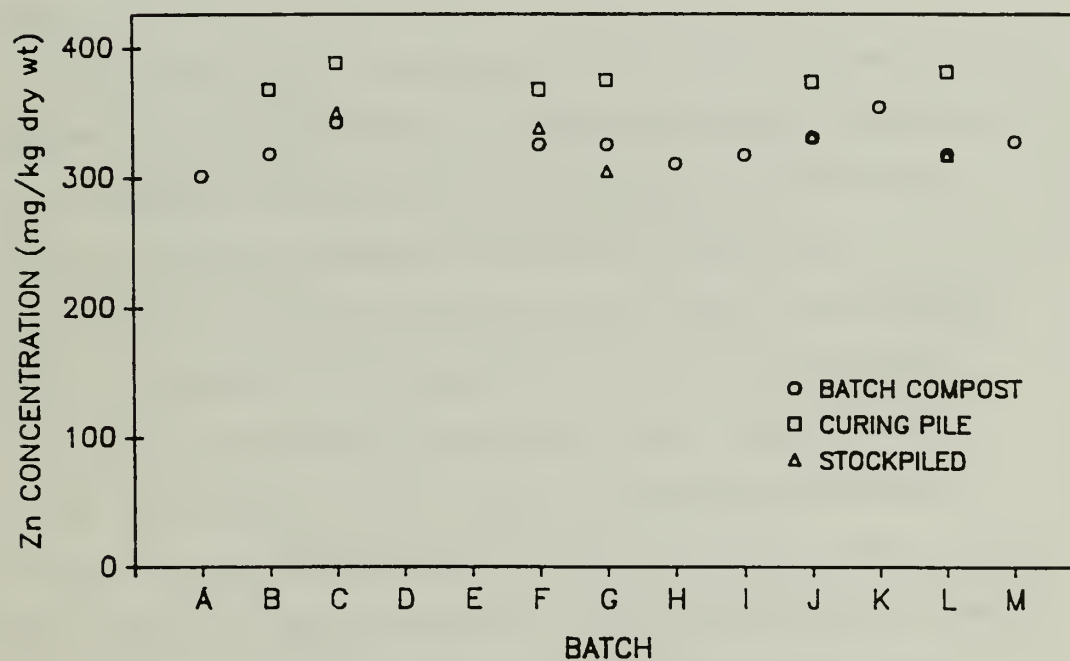


FIGURE 16 AVERAGE ZINC CONCENTRATIONS IN COMPOST SAMPLES

values for the stored compost samples are shown corresponding to those of the batch compost samples collected at approximately the same time. Table 15 contains the mean and median values of the percent differences in average metals concentrations between the batch and stored compost samples.

As the compost was stockpiled it was combined with the material from the previous batches. This compositing effect would be expected to reduce the variability of the of the metals concentrations in the stockpiled compost compared with the batch compost. The reduction in variability should increase the difference in the metals concentrations between the two sample types.

This effect is not noticeable in the data. In general, there appeared to be little difference between the metals concentrations of the stockpiled compost and the batch compost for all metals studied. With the exception of cadmium, average metals concentrations in the stockpiled compost samples were generally within 12 percent of the concentrations in the batch compost.

Since compost had not been added to the curing pile for several months prior to this study, the metals concentrations in the cured compost should reflect the metals concentrations in the batch compost of that prior period. The concentration of cadmium declined during the study period. This should increase the difference between the concentrations of the two sets of samples. Less of a difference would be expected for a metal such as copper,

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is essential for ensuring transparency and accountability in the organization's operations.

2. The second part outlines the various methods and tools used to collect and analyze data. This includes both traditional manual methods and modern digital technologies, highlighting the benefits of each approach.

3. The third part focuses on the role of the management team in overseeing the data collection process. It stresses the need for clear communication and coordination between different departments to ensure that data is collected consistently and accurately.

4. The fourth part discusses the challenges faced during the data collection process, such as incomplete data or discrepancies between different sources. It provides strategies to address these challenges and ensure the integrity of the data.

5. The fifth part describes the final steps in the data collection process, including the review and validation of the collected data. It emphasizes the importance of double-checking the data to ensure its accuracy before it is used for analysis.

6. The sixth part concludes the document by summarizing the key points and reiterating the importance of a systematic and thorough approach to data collection. It encourages the organization to continue to refine its processes and improve its data management practices over time.

TABLE 15 PERCENT DIFFERENCE BETWEEN AVERAGE METALS CONCENTRATIONS
IN BATCH COMPOST AND STORED COMPOST SAMPLES

METAL	PERCENT DIFFERENCE BETWEEN BATCH COMPOST AND		PERCENT DIFFERENCE BETWEEN BATCH COMPOST AND	
	STOCKPILED MEAN	MEDIAN	CURING PILE MEAN	MEDIAN
Cd	22.0	13.8	130.2	106.9
Cr	8.9	5.4	46.0	50.8
Cu	8.4	9.5	9.9	7.6
Ni	7.0	6.9	10.1	6.9
Pb	7.5	5.2	29.7	25.2
Zn	8.0	2.3	15.3	13.7

which was much less variable during and presumably prior to the study period. This was observed.

The differences between the average metals concentrations of the compost from the curing pile and the batch compost varied with the metal studied. The concentrations of copper, nickel and zinc in the cured compost samples were within 21 percent of the batch compost concentrations. The concentrations of chromium and lead were generally within 55 percent of the batch compost concentrations. The concentrations of cadmium differed by as much as 224 percent from the batch compost concentrations. The greater differences in the cadmium concentrations is likely due to the lower concentrations in the influent raw wastewater during the study period because of the installation of pretreatment by the industrial user during the study period. Plant records indicate that cadmium concentrations in the parent sludge during the study period were lower than those in previously composted sludge.

4.4 VARIABILITY OF THE DATA

The variability of several subsets of the data from this study was measured by the coefficient of variation (CV). Coefficients of variation were calculated for several subsets of the data from the metals analyses, each for a different time interval. Coefficients of variation were also calculated for the percent changes in metals concentrations measured in the batch

composting study. The results are presented in Appendix D. Table D1 contains the CV's of the metals concentrations over the entire study period for each type of sample. Table D2 contains the CV's of the metals concentrations in the sludge samples for each day they were collected. Table D3 contains the CV's of the metals concentrations in the stockpiled compost samples for each day they were collected. Table D4 contains the CV's of the average metals concentrations in the sludge and batch compost from each batch composted. Table D5 contains the CV's of the average metals concentrations in the sludge and batch compost over the entire study period. Table D6 contains the CV's of the percent change in metals concentrations for each metal.

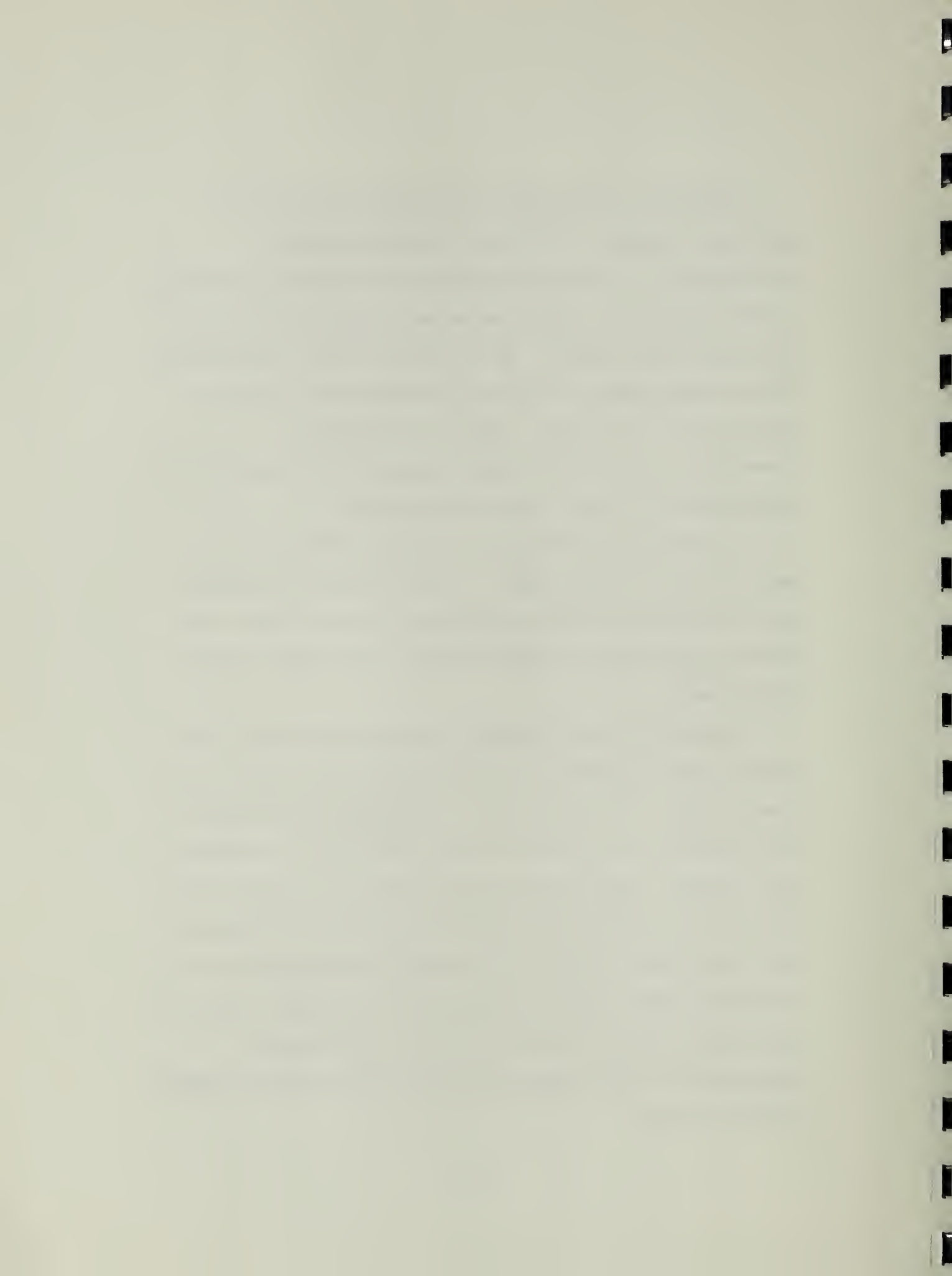
Variability was considered low if the CV was less than 25 percent. Variability was moderate if the CV was between 25 and 50 percent. If the CV was greater than 50 percent, then the variability was considered high (Sommers, 1976). No statistical analysis was performed to compare the variability of different sets of data.

The variability of the measured metals concentrations was low to moderate for all time periods. The daily CV's of the metals concentrations in the sludge samples (Table D2) ranged from 0 to 39 percent, but most values were less than ten percent. The CV's of the metals concentrations within each batch of sludge or batch compost (Table D4) was between 2 and 31 percent. Most of these values were less than ten percent as well.

Variability of the metals concentrations increased over longer time periods. The CV's of the average metals concentrations for the entire study period (Table D5) was between 4 and 37 percent for sludge samples and between 4 and 20 percent for batch compost samples. The CV's of the metals concentrations in the sludge samples for the entire study period (Table D1) varied from 6 to 39 percent. The CV's of the metals concentrations in the batch compost samples for the entire study period (Table D1) varied from 6 to 22 percent.

In general, concentrations of lead and cadmium were more variable than the other metals. In those variability analyses that included data sets for both sludge and batch compost, the metals concentrations were more variable in the sludge than the batch compost.

The variability of the metals concentrations in the stored compost samples was about the same as that in the sludge or batch compost samples. The daily CV's of the metals concentrations in the stockpiled and curing pile samples (Table D3) were between 1 and 31 percent. The CV's were lower on days in the early part of the study than on days near the end of the study. The reason for this is not known. The CV's of the metals concentrations of the stockpiled compost samples for the entire study period (Table D1) were between 12 and 24 percent. The CV's of the metals concentrations in the curing pile samples (Table D1) were between 9 and 37 percent.



The CV's of the change in metals concentrations were moderate to high for all metals. The CV for copper was 43 percent. The CV's for the other metals varied from 59 to 91 percent.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the results of this study, the following may be concluded:

1. The heavy metals concentrations in municipal sludge changed during composting. Typically, copper and nickel concentrations decreased while cadmium, chromium, lead, and zinc concentrations increased.
2. The changes in metals concentrations cannot be accounted for solely by changes in total solids. Other factors, such as degradation of organics, and loss of metals from the composting sludge via leaching must be involved.
3. The variability of the metals concentrations in the sludge and batch compost were typically low while the variability of the observed changes in sludge metals concentrations during composting were high (CV greater than 50 percent) for most metals studied.
4. Some heavy metals are removed from the sludge in the the liquid fraction during dewatering and composting (via leaching).

5.2 RECOMMENDATIONS

It is recommended that further study in this area be conducted to determine:

1. The impact of individual factors on the change in metals concentrations in sludge during composting. These factors include degradation of organics, organic supplementation from amendments, metal-amendment interactions, and loss of metals through desorption and leaching.
2. The process parameters of wastewater treatment and sludge disposal that influence these factors.
3. The feasibility of modification of these parameters to change the quality of the final sludge compost.
4. The impact of these changes in concentrations on the accuracy of compost sampling programs and on projections of compost quality.

REFERENCES

- Alibhai, K.R.K. et al, 1985, "Heavy Metal Binding to Digested Sludge", Water Research, 19:1483.
- Alpert, J.E., W. Taffel and E. Epstein, 1981, "Composting Sewage Sludge in Puerto Rico", Biocycle, 22 (1) 25.
- American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1985, Standard Methods for the Examination of Water and Wastewater, American Public Health Association, Washington, D.C.
- Aulenbach, D.B., M.A. Meyer, E. Beckwith, S. Joshi, C. Vasudevan and N.L. Clesceri, 1987, "Removal of Heavy Metals in POTW", Environmental Progress, 6 (2) 91.
- Bastian, R.K. and W.H. Whittington, 1976, "Municipal Sludge Management. EPA Construction Grants Program", presented at The Eighth Annual Cornell Waste Management Conference, Rochester, NY.
- Benson, R.E., 1980, "Natural Fixing Materials for the Containment of Heavy Metals in Landfills", Proceedings of the 12th MidAtlantic Industrial Waste Conference, Bucknell University, Lewisburg, PA.
- Black and Veatch, Inc., 1987, "Draft Report on Characterization of Residuals" prepared for the Massachusetts Water Resources Authority, 27 February.
- Bloomfield, C. and G. Pruden, 1975, "The Effects of Aerobic and Anaerobic Incubation on The Extractabilities of Heavy Metals in Digested Sewage Sludge", Environ Pollution, 8 (3) 217.
- Brown, H.G. et al, 1973, "Efficiency of Heavy Metals Removal in Municipal Sewage Treatment Plants", Environ. Letters, 5 (2) 103.
- Brown, W.E., 1985, "Metal Contamination of Sludge by Water Supply Systems", in Environmental Engineering. Proceedings of Specialty Conference, ASCE, Boston, MA.
- Brown, M.J. and J.N. Lester, 1979, "Metal Removal in Activated Sludge: The Role of Bacterial Extracellular Polymers", Water Research, 13:817.
- Camp, Dresser and McKee, Inc., 1982, "Engineering Assessment of Hot Acid Treatment of Municipal Sludge for Heavy Metal Removal", USEPA, EPA 600/2-82-014.

- Cantwell, F.F., J.S. Nielson and S.E. Hrudey, 1982, "Free Nickel Ion Concentration in Sewage by an Ion Exchange Column-Equilibration Method", Anal. Chem., 54:1498.
- Cappon, C.J., 1984, "Content and Chemical Form of Mercury and Selenium in Soil, Sludge and Fertilizer Materials", Water, Air and Soil Pollution, 22:95.
- Chaney, R.L., 1974, "Crop and Food Chain Effects of Toxic Elements in Sludges and Effluents", in Recycling Municipal Sludges and Effluents on Land, National Association of State Universities and Land Grant Colleges, Washington, D.C.
- Chen, K.Y., C.S. Young, T.K. Jen and N. Rohatgi, 1974, "Trace Metals in Wastewater Effluents", J. Water Pollution Control Federation, 46:2663.
- Cheng, M.H., J.W. Patterson and R.A. Minear, 1975, "Heavy Metals Uptake by Activated Sludge", J. Water Pollution Control Federation, 47:362.
- Davis, J. and J. Jacknow, 1975, "Heavy Metals in Wastewater in Three Urban Areas", J. Water Pollution Control Federation, 47:2292.
- Dean, J.G. et al, 1972, "Removing Heavy Metals from Wastewater", Environ Sci and Technology 6:518.
- Dean, R.B. and M.J. Seuss, 1985, "The Risk to Health of Chemicals in Sewage Sludge Applied to Land", Waste Mgt. and Research, 3:251.
- Donovan, J.F., D.F. Young and E. Epstein, 1985, "Composting Pilot Plant Results in Four New England Communities", presented to New England Water Pollution Control Association Annual Meeting, January.
- Doty, W.T., D.E. Baker and R.F. Shipp, 1977, "Chemical Monitoring of Sewage Sludge in Pennsylvania", J. Environ Quality, 6:421.
- Eckenfelder, W.W. and C.J. Santhanam (Eds.), 1981, Sludge Treatment, Marcel Dekker, New York.
- Ehret, D.J. and J.M. Walker, 1977, "The Role of Composting and Other Beneficial Use Options in Municipal Sludge Management", Proceedings National Conference on Composting of Municipal Residues and Sludges, Information Transfer Inc., Rockville, MD.
- Elinder, C.G. and E. Kessler, 1984, "Toxicity of Metals", in Utilisation of Sewage Sludge on Land: Rates of Application and

Long-Term Effects of Metals, D. Reidel Publishing Co., Dodrecht, Holland.

Ellis, J.C., and R.F. Lacey, 1980, "Sampling: Defining the Task and Planning the Scheme", Water Pollution Control, 79:452.

EPA, 1976, Application of Sewage Sludge to Cropland: Appraisal of Potential Hazards of the Heavy Metals to Plants and Animals, USEPA, EPA 430/9-76-013, Washington, D.C.

EPA, 1979a, "Criteria for Classification of Solid Waste Disposal Facilities and Practices", Federal Register, 44:53438.

EPA, 1979b, Process Design Manual. Sludge Treatment and Disposal, EPA 625/1-79-011, Cincinnati, OH.

EPA, 1982, "Fate of Priority Pollutants in Publicly Owned Treatment Works", EPA 440/1-82-303, Washington, D.C.

EPA, 1983, Process Design Manual. Land Application of Municipal Sludge, EPA 625/1-83-016, Cincinnati, OH.

Fair, G.M., J.C. Geyer and D.A. Okun, 1968, Water and Wastewater Engineering, Vol 2, John Wiley and Sons, New York

Farooq, S. and S. Akhlaque, 1982, "Oxidation of Biological Sludges with Ozone", J. Environ Sci and Health Part A, 17:609.

Fricke, C., C. Clarkson, E. Lomnitz and T. O'Farrell, 1985, "Comparing Priority Pollutants in Municipal Sludges", Biocycle, 26 (1) 35.

Fronk, C.A. et al, 1985, "Separation of Metals in Wastewater Sludge by Centrifugal Classification", Environ Progress, 4:269.

Furr, A.K., A.W. Lawrence, S.S.C. Tong, M.C. Grandolfo, R.A. Hofstader, C.A. Bache, W.H. Gutenmann and D.J. Lisk, 1976, "Multielement and Chlorinated Hydrocarbon Analysis of Municipal Sewage Sludges of American Cities", Environ Sci and Technology, 10:683.

Gleason, T.L., J.E. Smith and A.L. Page, 1984, "Utilization of Municipal Wastewater and Sludge on Land", Biocycle, 25 (4) 26.

Goldstein, N., 1987, "Sludge Composting on the Rise", Biocycle, 28 (10) 24.

Gould, M.S. and E.J. Genetelli, 1978, "Heavy Metal Complexation Behaviour in Anaerobically Digested Sludges", Water Research, 12:505.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is essential for ensuring transparency and accountability in the organization's operations.

2. The second part outlines the specific procedures and protocols that must be followed when recording transactions. This includes details on how data should be collected, stored, and reviewed to ensure its integrity and reliability.

3. The third part addresses the role of the management team in overseeing the record-keeping process. It stresses that management is responsible for ensuring that all staff are properly trained and that the necessary resources are provided to support the system.

4. The fourth part discusses the importance of regular audits and reviews to identify any discrepancies or areas for improvement. It suggests that these should be conducted at regular intervals and by independent parties to maintain objectivity.

5. The final part of the document provides a summary of the key points and reiterates the commitment to maintaining high standards of record-keeping throughout the organization.

Gould, M.S. and E.J. Genetelli, 1984, "Effects of Competition on Heavy Metal Binding by Anaerobically Digested Sludges", Water Research, 18:123.

Gurnham, C.F., B.A. Rose, H.R. Ritchie, W.T. Fetherston and A.W. Smith, 1979, Control of Heavy Metal Content of Municipal Wastewater Sludge, National Science Foundation.

Hanley, N., 1985, A Study of Metals Removal in Massachusetts Wastewater Treatment Facilities, Mass Dept of Environ Quality Engineering, Westborough, MA.

Hannah, S.A., B.M. Austern, A.E. Eralp, and R.H. Wise, 1986, "Comparative Removal of Toxic Pollutants by Six Wastewater Treatment Processes", J. Water Pollution Control Federation, 58:27.

Haug, R.T., 1980, Compost Engineering, Principles and Practices, Ann Arbor Science Publishers, Inc., Ann Arbor, MI

Higgins, A.J., 1984, "Design Specifications for Using Shredded Rubber Tires as a Bulking Agent", in Managing Sludge by Composting, Biocycle (ed.), The JG Press, Emmaus, PA.

Higgins, A.J., M.E. Singley, N. Nocitra, K. Callanan, B. Whitson and A. Singh, 1980, "Shredded Rubber Tires as a Bulking Agent", Compost Sci/Land Utilization, 21 (6) 20.

Huang, J.C., 1982, An Innovative Coprecipitation Technique for Removing Heavy Metals from Wastewater, EPA 600/2-82-053, Cincinnati, OH.

Jenkins, R.L., B.J. Scheybeler, M.L. Smith, R. Baird, M.P. Lo and R.T. Haug, 1981, "Metals Removal and Recovery from Municipal Sludge", J. Water Pollution Control Federation, 53:25.

Kamlet, K.S., 1979, "Superchlorination of Sewage Sludge: Adding Insult to Injury?", Sludge Magazine, 2:5.

Klein, L.A., M. Lang, N. Nash and S.L. Kirschner, 1974, "Sources of Metals in New York City Wastewater", J. Water Pollution Control Federation, 46:2653.

Koch, C.M. et al., 1982, "Impact of Pretreatment on Sludge Content of Heavy Metals", J. Water Pollution Control Federation, 54:339.

Leeper, G.W., 1978, Managing the Heavy Metals on the Land, Marcel Dekker, New York.

Le Gendre, G.R. and D.D. Runnels, 1975, "Removal of Dissolved Molybdenum from Wastewaters by Precipitates of Ferric Iron", Environ Sci and Technology 9:744.

Lester, J.N., 1983, "Significance and Behaviour of Heavy Metals in Wastewater Treatment Processes I. Sewage Treatment and Effluent Discharge", Sci Total Environ, 30:1.

Lester, J.N., R.M. Harrison and R. Perry, 1979, "The Balance of Heavy Metals Through a Sewage Treatment Works I. Lead, Cadmium and Copper", Sci Total Environ, 12:13.

Lomnitz, E., R. Bruins and L. Fradkin, 1985, "Screening Chemicals in Municipal Sludges", Biocycle, 26 (7) 52.

Lue-Hing, C., D.R. Zenz, B. Sawyer, E.Guth and S.W. Whitebloom, 1978, Impact of USEPA Solid Waste Disposal Criteria on Industrial Pretreatment Regulations, Metropolitan Sanitary District of Greater Chicago, Dept. of Research and Development, Report No. 78-21.

Masselli, J.W., N.W. Masselli and M.G. Burfond, 1967, "Sulfide Saturation for Better Digester Performance", J. Water Pollution Control Federation, 39:1369.

Metcalf and Eddy, 1986, Sludge Compost Marketing and Distribution Regulatory Requirements in the United States, USEPA, Boston, MA.

Mosher, D. and R.K. Anderson, 1977, Composting Sewage Sludge by High Rate Suction Aeration Techniques, USEPA, Washington, D.C.

Mumma, R.O., D.C. Raupach, J.P. Waldman, S.S.C. Tong and M.L. Jacobs, 1984, "National Survey of Elements and Other Constituents in Municipal Sewage Sludges", Archives of Environ Contamination and Toxicol, 13:75.

Nelson, P.O., A. Chung and M.C. Hudson, 1981, "Factors Affecting the Fate of Heavy Metals in the Activated Sludge Process", J. Water Pollution Control Federation, 53:1323.

Neufeld, R.D. and E.R. Hermann, 1975, "Heavy Metal Removal by Acclimated Activated Sludge", J. Water Pollution Control Federation, 47:310.

Obrist, W., 1987, "Material Balance of the Composting Process", Biocycle 28 (2) 32.

Oliver, B.G. and E.G. Cosgrove, 1974, "The Efficiency of Heavy Metal Removal by a Conventional Activated Sludge Treatment Plant", Water Research, 8:869.

Olthof, M. and L. Lancy, 1978, "Heavy Metal Contamination of Organic Sludges", presented at 51st annual conference of Water Pollution Control Federation.

Olver, J.W., W.C. Kreye and P.H. King, 1975, "Heavy Metal Release by Chlorine Oxidation of Sludges", J. Water Pollution Control Federation, 47:2490.

Parr, J.F., E. Epstein and G.B. Willson, 1978, "Composting Sewage Sludge for Land Application", Agric and Environ, 4 (2) 123.

Perry, R., P.W.W. Kirk, T. Stephenson and J.N. Lester, 1984, "Environmental Aspects of the use of NTA as a Detergent Builder", Water Research, 18:255.

Rossin, A.C., R.M. Sterritt and J.N. Lester, 1982, "The Influence of Process Parameters on the Removal of Heavy Metals in Activated Sludge", Water, Air and Soil Pollution, 17:185.

Rossin, A.C., R.M. Sterritt and J.N. Lester, 1983, "The Influence of Flow Conditions on the Removal of Heavy Metals in the Primary Sedimentation Process", Water, Air and Soil Pollution, 19:105.

Scott, D.S. and H. Horlings, 1975, "Removal of Phosphates and Metals from Sewage Sludge", Environ Sci and Technology, 9:849.

Solotto, B.V., and J.V. Farrell, 1972, Impact of Sludge Incineration on Air and Land, USEPA, Washington, D.C.

Sommers, L.E., 1977, "Chemical Composition of Sewage Sludges and Analysis of Their Potential Use as Fertilizers", J. Environ Quality, 6:225.

Sommers, L.E., D.W. Nelson and K.J. Yost, 1976, "Variable Nature of the Chemical Composition of Sewage Sludge", J. Environ Quality, 5:303.

Sterritt, R.M., M.J. Brown and J.N. Lester, 1981, "Metal Removal by Adsorption and Precipitation in the Activated Sludge Process", Environ Pollution Series A, 24:313.

Sterritt, R.M. and J.N. Lester, 1981a, "Concentrations of Heavy Metals in Forty Sewage Sludges in England", Water, Air and Soil Pollution, 14:125.

Sterritt, R.M. and J.N. Lester, 1981b, "The Influence of Sludge Age on Heavy Metal Removal in the Activated Sludge Process", Water Research, 15:59.

Sterritt, R.M. and J.N. Lester, 1982, "Speciation of Copper and Manganese in Effluents from the Activated Sludge Process", Environ Pollution Series A, 27:37.

Stoveland, S., M. Astruc, J.N. Lester and R. Perry, 1979, "The Balance of Heavy Metals Through a Sewage Treatment Works II. Chromium, Nickel and Zinc", Sci Total Environ, 12:25.

Stoveland, S. and J.N. Lester, 1980, "A Study of Factors Which Influence Metal Removal in the Activated Sludge Process", Sci Total Environ, 16:37.

Sukenik, W.H., P.H. King and J.W. Olver, 1977, "Chlorine and Acid Conditioning of Sludge", J. Environmental Engineering Division, Proc. American Society of Civil Engineers, 103:1013.

Thompson, K.C. and K. Wagstaff, 1980, "Simplified Method for the Determination of Cadmium, Chromium, Copper, Nickel, and Zinc in Sewage Sludge Using Atomic-absorbtion Spectrophotometry", Analyst, 105:883.

Tyagi, R.D. and Couillard, D., 1987, "Bacterial Leaching of Metals from Digested Sewage Sludge", Process Biochemistry

Waldron, H.A. (Ed.), 1980, Metals in the Environment, Academic Press, London.

Wood, D.K. and G. Tchobanoglous, 1975, "Trace Elements in Biological Waste Treatment", J. Water Pollution Control Federation, 47:1933.

Wozniak, D.J. and J.Y.C. Huang, 1982, "Variables Affecting Metal Removal from Sludge", J. Water Pollution Control Federation, 54:1574.

Yost, K.J. and R.F. Wukasz, 1983, "Pollutant Sources and Flows in a Municipal Sewage System", Environ Monitoring and Assess., 3 (10) 61.

Zenz, D.R., B.T. Lyman, C. Lue-Hing, R.R. Rimkus and T.D. Hinesly, 1975, USEPA Guidelines on Sludge Utilization and Disposal-A Review of its Impact Upon Municipal Wastewater Treatment Agencies, Metropolitan Sanitary District of Greater Chicago, Dept of Research and Development, Report No. 75-20

APPENDIX A

SUMMARY OF SELECTED STATES' REGULATIONS ON LAND APPLICATION

Connecticut

Regulating Agency: Department of Environmental Protection
Type of Rules: Guidelines
Type of Approval Required: Site approval
Typical Interval Between Sludge Analyses: 3 months
Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn
Disposal Options Specified: Land application
Criteria for Metals Regulations: Maximum permissible metals concentrations, maximum cumulative loading limits
(See Table A1)

Delaware

Regulating Agency: Department of Natural Resources and Environmental Control
Type of Rules: Draft regulations (published May, 1987)
Type of Approval Required: Site Approval
Typical Interval Between Sludge Analyses: 4 months
Metals Regulated: Cd, Cr, Cu, Ni, Pb, Hg, Zn
Disposal Options Specified: Agricultural use, land reclamation, surface land disposal, and sludge distribution
Criteria for Metals Regulations: Land application must conform to federal regulations and guidelines. Maximum sludge metals concentrations set for sludge distribution (table A2)

Maine

Regulating Agency: Department of Environmental Protection
Type of Rules: Regulations
Type of Approval Required: Site approval or program approval
Typical Interval Between Sludge Analyses: 1,3 or 12 months
Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn
Criteria for Metals Regulation: Maximum Permissible Concentrations (Table A3) and Maximum cumulative loading (Table A4)

Table A1 Connecticut Sludge Metals Limitations

<u>Metal</u>	<u>Maximum Permissible Concentration (mg/kg)</u>	<u>Maximum Cumulative Loading (kg/ha)</u>
Cd	25	3.37
Cr	1000	336.8
Cu	1000	84.2
Pb	1000	336.8
Hg	10	not regulated
Ni	200	33.7
Zn	2500	168.4

Table A2 Delaware Maximum Sludge Metals Concentrations for Sludge Distribution (mg/kg)

Cd	12.5
Cu	500
Pb	500
Hg	5
Ni	100
Zn	1250

Table A3 Maine Maximum Permissible Sludge Metals Concentrations (mg/kg)

Cd	10
Cr	1000
Cu	1000
Pb	700
Hg	10
Ni	200
Zn	2000

Table A4 Maine Maximum Cumulative Metals Loading (kg/ha)

	<u>Soil Cation Exchange Capacity</u>		
	<u><5</u>	<u>5-15</u>	<u>>15</u>
Cd	2.5	5	5
Cr	250	500	1000
Cu	125	250	500
Pb	500	1000	2000
Ni	250	500	1000
Zn	50	100	200

Massachusetts

Regulating Agency: Department of Environmental Protection
Type of Rules: Regulations
Type of Approval Required: Site approval required for Type II and Type III sludges
Typical Interval Between Sludge Analyses: 1, 3 or 6 months
Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn, Mo, B
Disposal Options Specified: Land application and distribution
Criteria for Metals regulation: Sludge classified Type I, II or III by metals concentrations (Table A5). Type II and III subject to maximum cumulative loading limits (Table A6), maximum annual cadmium loading and maximum annual soil lead concentration.

New Hampshire

Regulating Agency: Department of Environmental Services
Type of Rules: Regulations and guidelines
Type of Approval Required: Site approval required (except for small scale manual application).
Typical Interval Between Sludge Analyses: 4 or 12 months
Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn
Disposal Options Specified: Agricultural use, land reclamation, forest application, governmental use, composting and landfiling
Criteria for Metals Regulations: Maximum permissible concentration for agricultural use (Table A7), maximum lifetime loading rate for agricultural use (Table A8), reclaimed land, highway buffer zones and forested land (Table A9) and maximum annual cadmium loading.

New Jersey

Regulating Agency: Department of Environmental Protection
Type of Rules: Regulations
Type of Approval Required: Permit required
Typical Interval Between Sludge Analyses: 1, 3, 6 or 12 months
Metals Regulated: As, Cd, Cr, Cu, Pb, Hg, Ni, Zn
Disposal Options Specified: Land application, composting and landfiling
Criteria for Metals Regulation: Maximum permissible concentrations (Class A sludge can be applied to a site for 40 years and Class B sludge can be applied for 20 years before cumulative load limits are reached) (Table A10)

Table A5 Massachusetts Sludge Classification Criteria
(mg/kg)

	<u>Type I</u>	<u>Type II</u>	<u>Type III</u>
Cd	<2	25	>Type II
Cr	<1000	1000	>Type II
Cu	<1000	1000	>Type II
Ni	<200	200	>Type II
Pb	<300	1000	>Type II
Hg	<10	10	>Type II
Zn	<2500	2500	>Type II
Mo	<10	10	>Type II
B	<300	300	>Type II

Table A6 Massachusetts Maximum Cumulative Metals Loadings
(lb/ac)

	<u>Soil Cation Exchange Capacity (meq/100g)</u>	
	<u>≤5</u>	<u>≥5</u>
Cd	2	25
Cu	125	250
Ni	50	100
Zn	250	500

Table A7 New Hampshire Maximum Permissible Metals
Concentrations for Agricultural Use (mg/kg)

Cd	10
Cr	1000
Cu	1000
Pb	700
Hg	10
Ni	200
Zn	2000

Table A8 New Hampshire Maximum Lifetime Application Rate
for Agricultural Use (lb/ac)

	Soil Cation Exchange Capacity		
	<u>≤5</u>	<u>5-15</u>	<u>>15</u>
Cd	2.2	4.5	9
Cr	125	250	500
Cu	125	250	500
Pb	500	1000	2000
Hg	0.5	1	2
Ni	50	100	200
Zn	250	500	1000

Table A9 New Hampshire Maximum Lifetime Application Rates
(lb/ac)

	<u>Highway Buffer Zones</u>	<u>Reclaimed Land</u>	<u>Forested Land</u>
Cd	9	4.5	4.5
Cr	500	250	250
Cu	500	250	250
Pb	2000	1000	1000
Hg	2	1	1
Ni	200	100	100
Zn	1000	500	500

Table A10 New Jersey Maximum Permissible Metals
Concentrations (mg/kg)

	<u>Class A</u>	<u>Class B</u>
Cd	20	40
Cr	600	1200
Pb	2400	4800
Ni	625	1250
Zn	1200	1200
Cr	1000	1000
Hg	10	10
As	10	10

New York

Regulating Agency: Department of Environmental Conservation

Type of Rules: Regulations and Guidelines

Type of Approval Required: Site approval required

Typical Interval Between Sludge Analyses: 1,3 or 6 months for land application and weekly, monthly or semiannually for composting and distribution

Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn

Disposal Options Specified: Agricultural use, land reclamation, other vegetative covers and composting and distribution

Criteria for Metals Regulation: Maximum permissible concentration for land application (Table A11), maximum permissible concentration for composting and distribution (Table A12), cumulative loading limits for land application (Table A13) and annual cadmium loading limits

Pennsylvania

Regulating Agency: Bureau of Waste Management

Type of Rules: Proposed Regulations (published June, 1987)

Type of Approval Required: Site approval required for land application. Program approval required for composting.

Typical Interval Between Sludge Analyses: 4 months

Disposal Options Specified: Agricultural use, land reclamation, land disposal and composting and distribution

Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn

Criteria for Metals Regulation: None specified

Vermont

Regulating Agency: Agency of Natural Resources

Type of Rules: Guidelines

Type of Approval Required: Site approval required

Typical Interval Between Sludge Analyses: 6 or 12 months

Metals Regulated: Cd, Cr, Cu, Pb, Hg, Ni, Zn

Disposal Options Specified: Land application and landfilling

Criteria for Metals Regulation: Maximum Permissible Concentrations (Table A14)

Table A11 New York Maximum Permissible Metals
Concentrations for Land Application
(mg/kg)

Cd	25
Cr	1000
Cu	1000
Pb	1000
Hg	10
Ni	200
Zn	2500

Table A12 New York Maximum Permissible Metals
Concentrations for Composting and Distribution
(mg/kg)

Cd	10
Cr	1000
Cu	1000
Pb	250
Hg	10
Ni	200
Zn	2500

Table A13 New York Cumulative Metals Loading Limits
(kg/ha)

Cd	5
Cu	125
Pb	500
Ni	50
Zn	250

Table A14 Vermont Maximum Permissible Metals Concentrations
(mg/kg)

Cd	25
Cr	1000
Cu	1000
Pb	1000
Hg	10
Ni	200
Zn	2500

Virginia

Regulating Agency: State Water Control Board

Type of Rules: Regulations and guidelines

Type of Approval Required: Site approval required

Typical Interval Between Sludge Analyses: not specified

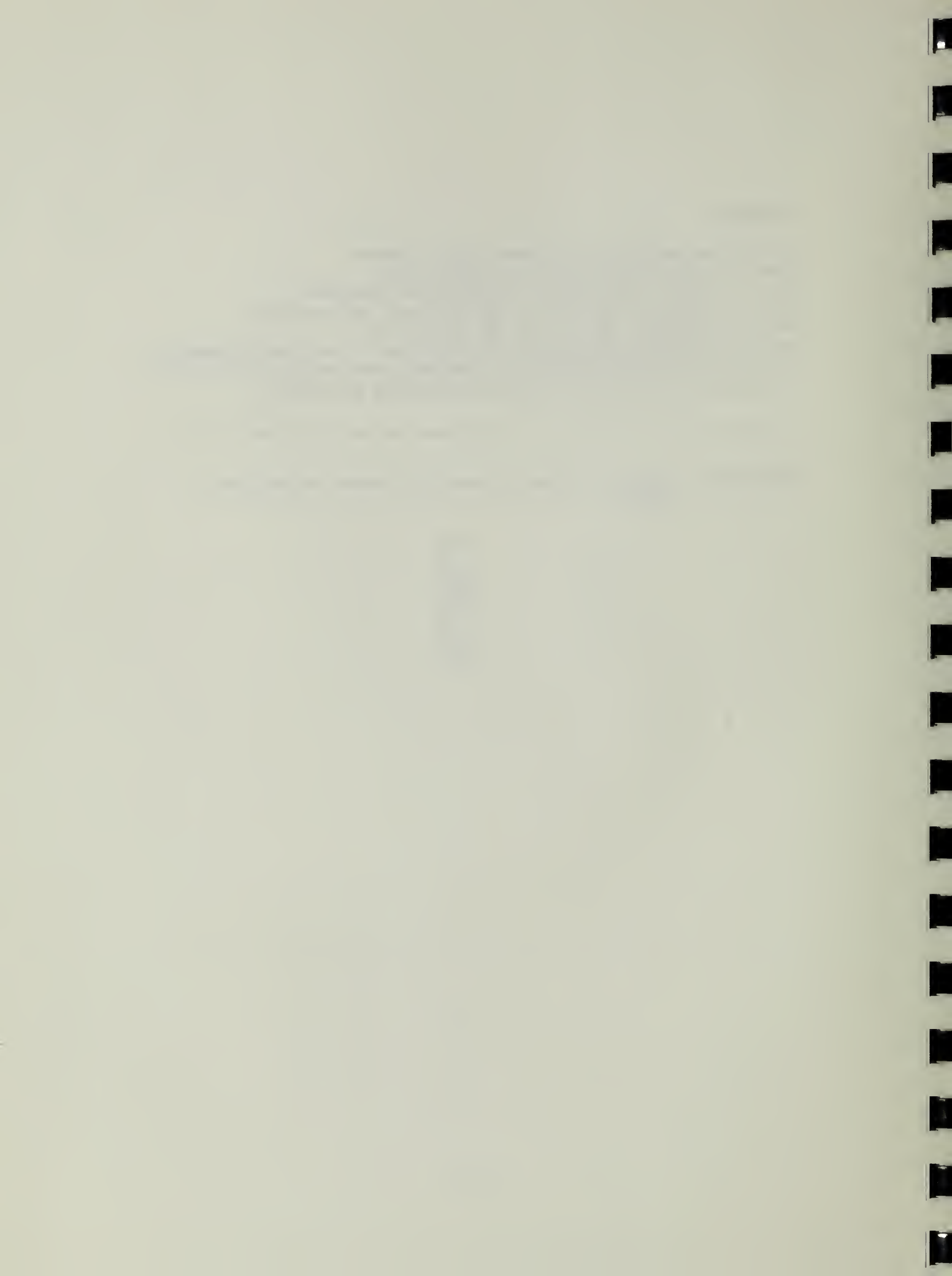
Metals Regulated: B, Cd, Cu, Pb, Hg, Ni, Zn

Disposal Options Specified: Land application and land reclamation

Criteria for Metals Regulation: Maximum permissible concentrations (Table A15) and maximum cumulative loading guidelines

Table A15 Virginia Maximum Permissible Metals Concentration
(mg/kg)

B	100
Cd	25
Cu	1000
Pb	1000
Hg	15
Ni	200
Zn	2500



APPENDIX B

ATOMIC ABSORPTION SPECTROPHOTOMETRY ANALYTICAL CONDITIONS

TABLE B1 ATOMIC ABSORPTION SPECTROPHOTOMETER OPERATING CONDITIONS

Element	Wavelength (nm)	Atomizer	Fuel/ Oxidant	Linear Range (mg/L)	Sensitivity (mg/L)	Detection Limit (mg/L) (3)
Cd	228.8	flame (lean)	Ac/Air (1)	0 to 2.0	0.028	0.005
Cr	357.9	flame (rich)	Ac/Air	0 to 5.0	0.078	0.005
Cu	324.8	flame (lean)	Ac/Air	0 to 5.0	0.077	0.005
Ni	341.5	flame (lean)	Ac/Air	0 to 20.0	0.40	0.004
Pb	217.0 (2)	flame (lean)	Ac/Air	0 to 20.0	0.19	0.01
Zn	213.9	flame (lean)	Ac/Air	0 to 1.0	0.018	0.0008

(1) Acetylene/Air

(2) Background correction used

(3) Under operating conditions employed

TABLE B2 METALS CONCENTRATIONS IN PREPARED STANDARDS FOR ATOMIC
ABSORPTION SPECTROPHOTOMETRY (mg/l)

Metal	Standard No.			
	1	2	3	4
Cadmium	0.4	1.0	2.0	4.0
Chromium	0.4	1.0	2.0	4.0
Copper	1.4	3.5	7.0	14.0
Nickel	0.6	1.5	3.0	6.0
Lead	0.2	0.5	1.0	2.0
Zinc	0.202	0.505	1.01	2.02

TABLE B3 RESULTS OF QC SAMPLE ANALYSES (mg metal/l)

Sesssion No.	Cd	Cr	Cu	Ni	Pb	Zn
1	0.85	1.72	11.71	2.86	1.19	1.147
2	0.88	1.46	10.96	2.75	1.10	1.140
3	0.86	1.62	10.90	2.80	1.13	1.122
4	0.86	1.43	10.78	2.75	1.04	1.125
5	0.86	1.44	11.30	2.88	1.03	1.118
6	0.85	1.14	11.30	2.89	1.15	1.111
7	0.86	1.38	11.19	2.89	1.11	1.083
mean	0.86	1.46	11.16	2.83	1.11	1.120
std dev	0.01	0.17	0.29	0.06	0.05	0.02
% C of V	1.08	11.70	2.61	2.08	4.80	1.72

APPENDIX C
DATA FROM HEAVY METALS ANALYSES

TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES

BATCH	DATE	TYPE	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
	COLLECTED	(1)		Cd	Cr	Cu	Ni	Pb	Zn
A	01/21/88	S	638	42	75	425	167	59	276
A	01/21	S	639	40	73	404	159	56	286
A	01/21	S	640	41	74	415	148	67	258
A	01/21	S	635	36	69	404	155	50	236
A	01/21	S	636	42	77	428	161	61	272
A	01/21	S	637	42	76	419	165	67	267
A	01/21	S	632	40	75	404	159	56	262
A	01/21	S	633	41	74	415	157	57	261
A	01/21	S	634	40	74	392	149	57	260
A	01/22	S	665	42	96	484	167	67	273
A	01/22	S	664	41	98	492	166	68	269
A	01/22	S	663	41	98	465	164	52	255
A	01/22	S	662	40	96	469	162	59	269
A	01/25	S	661	45	98	467	250	57	268
A	01/25	S	660	46	92	481	254	62	262
A	01/25	S	659	46	93	462	269	55	254
A	01/25	S	658	48	92	498	255	58	267
A	03/01	C	897	47	94	453	162	66	287
A	03/01	C	898	49	98	473	171	68	298
A	03/01	C	899	46	91	413	156	71	284
A	03/01	C	900	53	107	444	180	86	336
A	03/01	C	893	43	90	434	168	72	312
A	03/01	C	894	47	93	440	166	67	283
A	03/01	C	895	48	94	437	161	74	297
A	03/01	C	896	45	98	439	165	78	307
B	01/27	S	654	45	92	461	235	48	261
B	01/27	S	655	47	88	488	239	57	255
B	01/27	S	656	47	90	483	242	59	265
B	01/27	S	657	47	85	498	246	58	268
B	01/28	S	653	44	87	474	228	57	273
B	01/28	S	652	43	97	484	222	60	256
B	01/28	S	651	45	92	499	233	54	274
B	01/29	S	650	42	95	477	213	71	317
B	01/29	S	649	42	92	465	208	53	261
B	01/29	S	648	41	90	478	212	50	255
B	02/01	S	645	40	84	499	246	71	301

MEMORANDUM FOR THE RECORD

TO : Mr. Tolson

FROM : Mr. [Name]

SUBJECT: [Subject]

[The following text is extremely faint and largely illegible. It appears to be a memorandum detailing a meeting or discussion, possibly involving the [Name] mentioned in the 'FROM' line. The text is organized into paragraphs and possibly includes a list or table of items discussed.]

TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE COLLECTED	TYPE (1)	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
				Cd	Cr	Cu	Ni	Pb	Zn
B	02/01	S	644	40	89	503	249	68	274
B	02/01	S	647	39	91	493	249	88	275
B	02/01	S	646	41	105	533	266	70	292
B	03/03	C	817	45	95	431	189	71	318
B	03/03	C	818	43	91	415	183	69	295
B	03/03	C	819	45	96	438	188	86	316
B	03/03	C	820	47	95	428	190	76	338
B	03/03	C	821	61	122	493	211	92	370
B	03/03	C	822	45	93	449	185	78	297
B	03/03	C	823	45	96	404	187	70	302
B	03/03	C	824	44	91	404	182	64	306
C	02/09	S	681	31	79	472	218	53	246
C	02/09	S	641	33	84	479	217	62	602
C	02/09	S	642	32	81	501	215	63	289
C	02/09	S	643	32	73	514	223	55	266
C	02/10	S	677	33	74	587	230	61	301
C	02/10	S	680	33	68	540	208	59	264
C	02/10	S	679	33	74	538	214	68	264
C	02/10	S	678	33	69	558	214	59	269
C	02/11	S	676	33	71	533	214	56	264
C	02/11	S	675	34	73	546	208	61	268
C	02/11	S	674	32	78	523	211	57	258
C	02/11	S	673	34	69	557	214	58	284
C	03/15	C	808	49	112	506	208	86	346
C	03/15	C	809	48	109	467	202	79	352
C	03/15	C	810	42	99	419	177	77	313
C	03/15	C	814	49	114	489	207	84	341
C	03/15	C	811	64	132	487	209	97	372
C	03/15	C	812	42	102	474	194	77	340
C	03/15	C	813	51	111	503	210	97	332
C	03/15	C	815	45	99	449	191	82	336
D	02/19	S	672	27	74	534	203	69	274
D	02/19	S	671	28	76	546	215	61	285
D	02/19	S	670	27	77	535	212	62	268

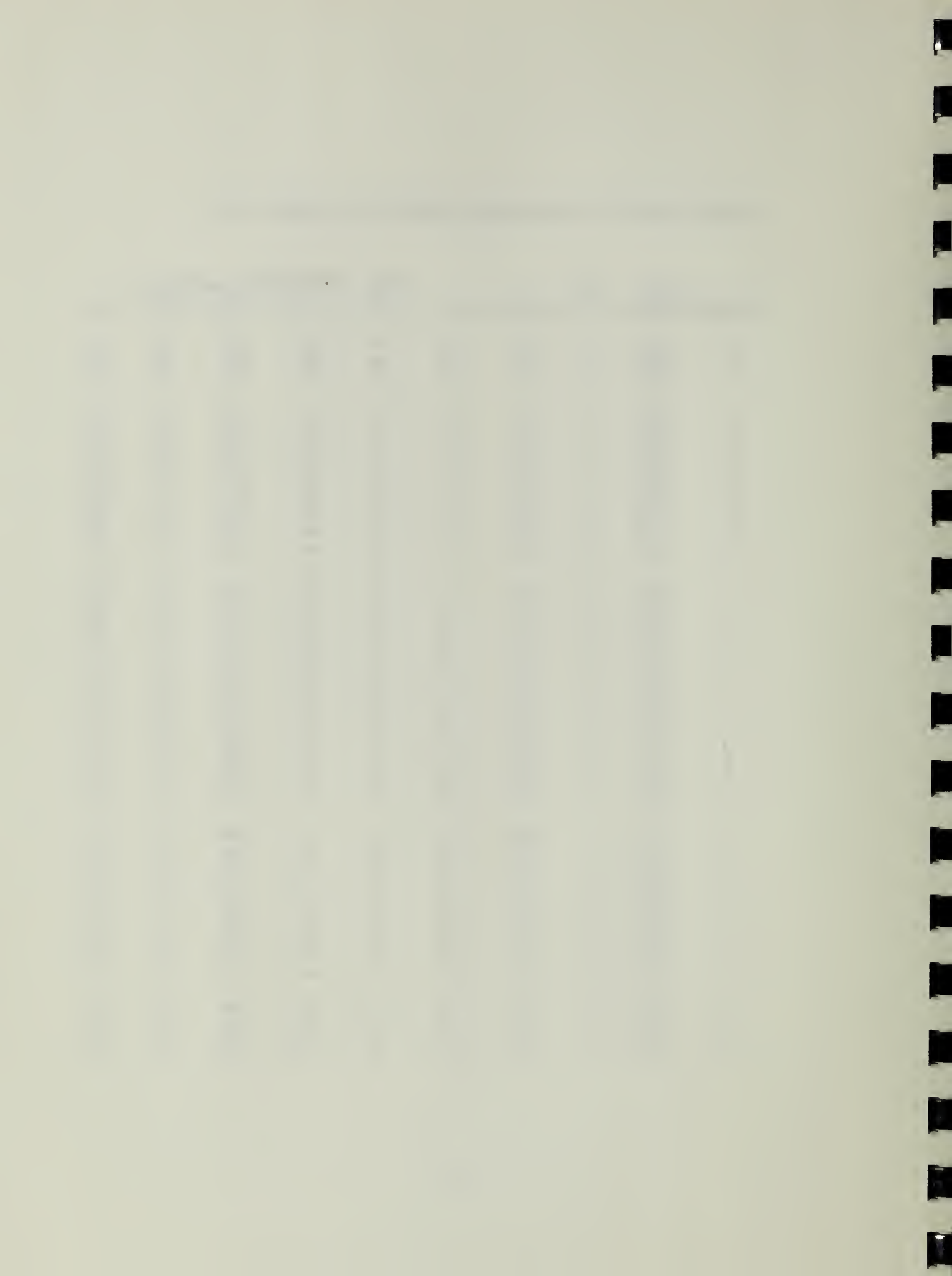


TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE	TYPE	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
	COLLECTED	(1)		Cd	Cr	Cu	Ni	Pb	Zn
D	02/22	S	669	27	70	530	275	64	282
D	02/23	S	1001	25	69	518	263	64	270
D	02/23	S	1002	24	75	518	258	69	261
D	02/23	S	1003	24	73	530	268	69	273
D	02/23	S	1004	28	75	519	261	67	268
D	02/24	S	1005	27	72	528	260	62	268
D	02/24	S	1006	29	78	541	262	66	276
D	02/24	S	1007	28	74	553	253	67	272
D	02/24	S	1008	29	76	538	254	63	281
E	03/01	S	1009	27	73	516	268	62	297
E	03/01	S	1010	29	78	528	268	72	287
E	03/01	S	1012	26	76	539	273	64	306
E	03/02	S	1013	28	76	546	268	75	306
E	03/02	S	1014	27	76	529	270	67	303
E	03/02	S	1011	28	76	544	271	64	307
E	03/03	S	1015	26	77	542	281	69	326
E	03/03	S	1016	28	82	524	269	70	305
E	03/03	S	1017	47	83	518	258	62	297
E	03/03	S	1018	25	75	499	268	62	321
E	03/04	S	1019	27	84	532	272	62	300
E	03/04	S	1020	27	87	524	263	67	317
E	03/04	S	1021	25	84	522	271	67	301
F	03/07	S	1022	24	75	491	275	59	296
F	03/07	S	1023	23	77	478	268	67	281
F	03/07	S	1024	22	79	495	267	60	293
F	03/07	S	1025	24	81	505	271	61	284
F	03/08	S	628	23	69	500	273	60	278
F	03/08	S	629	23	76	499	253	58	243
F	03/08	S	630	25	80	498	277	70	328
F	03/08	S	631	24	81	497	284	59	282
F	03/09	S	625	23	79	490	275	63	288
F	03/09	S	626	23	79	501	270	64	291
F	03/09	S	627	22	78	517	265	60	303
F	03/10	S	624	21	72	497	248	61	280
F	03/10	S	621	34	76	504	250	65	273
F	03/10	S	622	22	73	508	256	67	290

TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE COLLECTED	TYPE (1)	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
				Cd	Cr	Cu	Ni	Pb	Zn
F	03/10	S	623	20	71	484	248	61	289
F	04/13	C	882	38	93	468	243	69	326
F	04/13	C	883	38	96	463	241	73	323
F	04/13	C	884	37	103	448	232	69	350
F	04/13	C	885	38	93	445	229	68	309
F	04/13	C	875	35	97	449	240	70	301
F	04/13	C	876	34	103	313	198	56	289
F	04/13	C	877	43	101	471	244	69	338
F	04/13	C	878	55	134	415	234	82	363
G	03/18	S	1026	16	61	459	221	51	297
G	03/18	S	1027	17	77	479	238	56	254
G	03/18	S	1028	17	74	487	234	54	266
G	03/21	S	1029	18	76	448	235	51	260
G	03/21	S	1030	17	68	492	231	49	268
G	03/21	S	1031	18	71	478	242	54	255
G	03/22	S	1032	17	66	464	223	53	258
G	03/22	S	1033	18	67	511	246	57	279
G	03/22	S	1034	17	63	501	240	52	264
G	03/23	S	1035	16	62	459	216	53	267
G	03/23	S	1036	17	71	484	229	53	250
G	03/23	S	1037	16	69	473	223	46	251
G	03/24	S	1038	16	65	487	221	57	277
G	03/24	S	1039	16	69	491	225	51	252
G	03/24	S	1040	16	68	490	224	48	256
G	03/25	S	1041	17	69	463	207	54	268
G	03/25	S	1042	17	71	483	221	55	261
G	03/25	S	1043	18	70	447	209	55	239
G	04/27	C	858	32	90	443	222	66	305
G	04/27	C	859	31	91	458	226	69	328
G	04/27	C	860	30	92	452	226	65	306
G	04/27	C	861	30	90	424	215	67	344
G	04/27	C	862	32	94	463	235	73	340
G	04/27	C	863	33	92	438	230	62	346
G	04/27	C	864	33	91	458	233	66	316
G	04/27	C	865	32	96	472	302	66	312

TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE	TYPE	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
	COLLECTED	(1)		Cd	Cr	Cu	Ni	Pb	Zn
H	03/31	S	925	20	64	504	195	60	258
H	03/31	S	926	17	66	525	197	69	264
H	03/31	S	927	15	65	522	197	60	267
H	04/01	S	928	17	73	521	195	59	255
H	04/01	S	930	15	68	512	193	60	247
H	04/01	S	931	15	68	524	193	83	270
H	04/01	S	932	15	70	512	196	52	250
H	04/04	S	933	14	75	510	190	61	249
H	04/04	S	934	13	74	498	189	57	246
H	04/04	S	935	13	74	499	187	65	238
H	04/04	S	936	13	74	492	184	60	244
H	05/09	C	866	27	77	460	178	69	303
H	05/09	C	867	29	79	477	183	77	336
H	05/09	C	868	29	80	447	177	72	321
H	05/09	C	869	28	75	485	177	66	300
H	05/09	C	870	23	68	422	169	58	277
H	05/09	C	871	29	74	444	172	66	323
I	04/11	S	937	15	71	523	186	60	260
I	04/11	S	938	15	71	537	184	81	255
I	04/11	S	940	15	68	513	180	54	246
I	04/12	S	941	15	67	516	182	62	250
I	04/12	S	942	15	71	514	176	52	300
I	04/12	S	943	15	74	542	179	54	289
I	04/12	S	944	15	77	554	175	52	275
I	04/13	S	945	15	70	513	185	57	273
I	04/13	S	946	15	83	480	167	55	292
I	04/13	S	947	16	78	501	169	49	280
I	04/13	S	948	15	77	493	166	50	254
I	05/18	C	808	29	83	467	175	67	313
I	05/18	C	809	31	83	483	182	69	346
I	05/18	C	811	28	80	468	178	67	301
I	05/18	C	812	33	85	461	173	66	305
I	05/18	C	813	30	81	492	178	74	327
I	05/18	C	819	30	81	471	179	69	311

TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE	TYPE	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
	COLLECTED	(1)		Cd	Cr	Cu	Ni	Pb	Zn
J	04/19	S	1044	17	74	501	172	55	291
J	04/19	S	1045	16	81	497	198	54	292
J	04/19	S	1046	16	83	508	200	64	279
J	04/19	S	1047	16	82	514	181	54	306
J	04/20	S	1049	15	79	491	170	52	287
J	04/20	S	1050	14	79	479	165	67	263
J	04/21	S	950	14	77	475	164	51	247
J	04/21	S	949	15	82	506	173	52	270
J	04/22	S	618	15	78	450	196	52	244
J	04/22	S	616	18	82	501	169	50	294
J	04/22	S	617	17	83	507	174	58	300
J	04/25	S	1052	19	79	464	165	51	254
J	04/25	S	1053	17	76	489	214	57	268
J	04/25	S	1054	17	84	475	165	84	306
J	04/25	S	1055	19	83	506	177	56	305
J	05/25	C	829	33	93	496	183	78	339
J	05/25	C	821	29	78	467	159	74	306
J	05/25	C	826	32	97	487	176	73	331
J	05/25	C	810	35	96	481	179	73	335
J	05/25	C	814	35	88	484	181	73	335
J	05/25	C	815	32	85	473	174	70	331
K	05/03	S	1059	17	83	502	184	113	351
K	05/03	S	1058	19	108	500	193	115	323
K	05/03	S	1057	16	82	480	178	124	338
K	05/03	S	1056	18	82	504	185	110	337
K	05/04	S	1060	18	78	504	187	110	349
K	05/04	S	1061	23	79	486	187	108	338
K	05/04	S	1062	19	84	477	189	116	335
K	05/04	S	1063	21	87	509	192	128	372
K	05/05	S	1064	31	75	584	207	97	337
K	05/05	S	1065	28	76	489	211	93	320
K	05/05	S	1066	27	77	506	201	95	313
K	05/05	S	1067	27	83	504	210	95	330
K	06/08	C	823	34	86	463	179	102	375
K	06/08	C	824	38	98	476	192	110	365

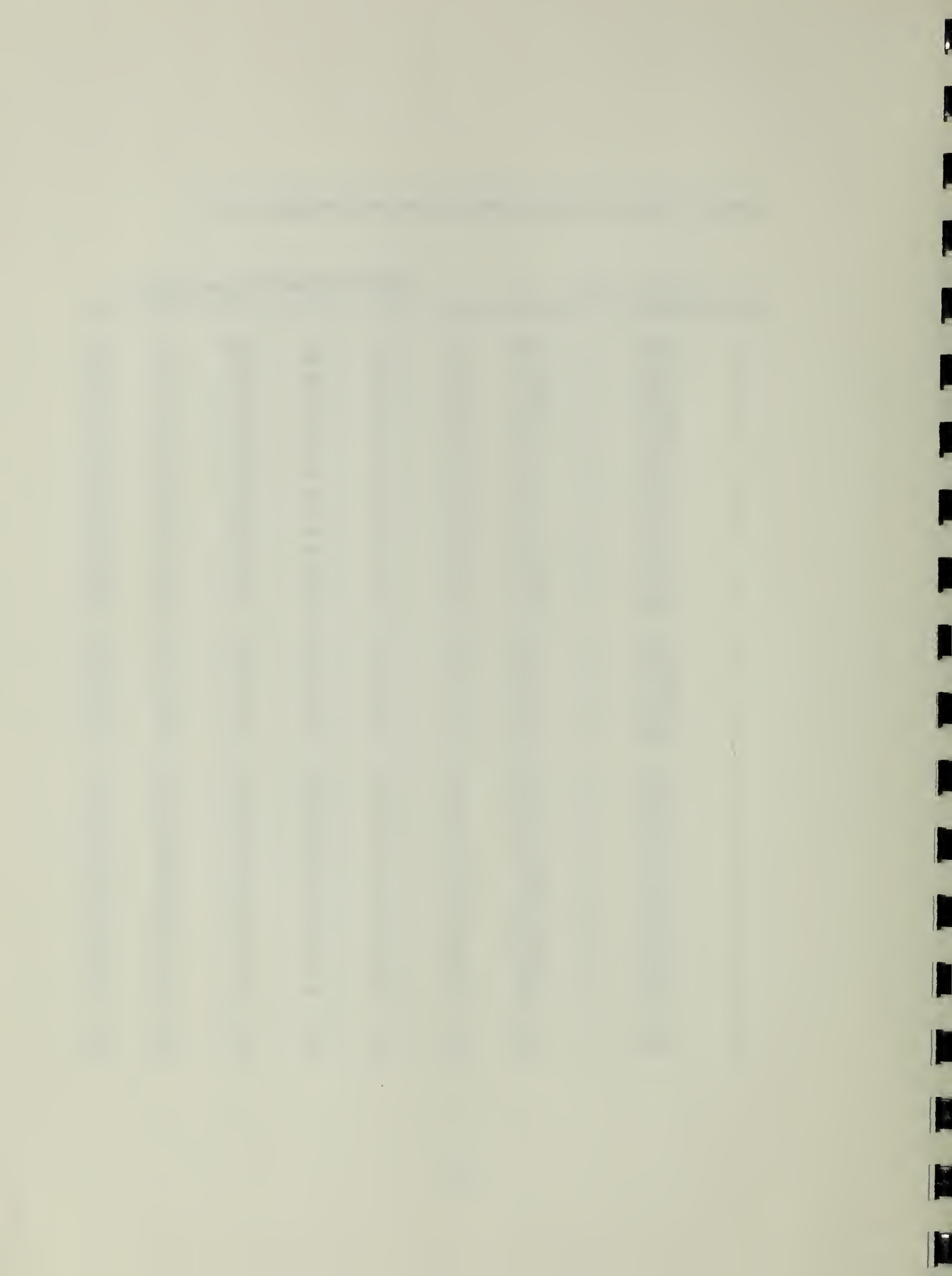


TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE COLLECTED	TYPE (1)	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
				Cd	Cr	Cu	Ni	Pb	Zn
K	06/08	C	841	36	101	486	189	103	357
K	06/08	C	817	35	95	465	181	97	346
K	06/08	C	820	37	97	467	186	92	340
K	06/08	C	831	35	89	479	182	98	339
L	05/11	S	1077	25	76	519	207	93	328
L	05/11	S	1073	44	76	542	214	99	334
L	05/11	S	1074	26	76	501	202	94	318
L	05/11	S	1075	30	90	499	227	96	333
L	05/12	S	953	27	61	483	205	83	331
L	05/12	S	951	34	60	481	203	83	327
L	05/12	S	952	38	35	481	202	100	318
L	05/13	S	954	24	44	436	190	67	294
L	05/13	S	955	35	72	475	202	85	308
L	05/13	S	956	48	34	476	196	75	319
L	05/16	S	957	22	55	453	215	77	295
L	05/16	S	958	26	56	448	214	74	305
L	05/16	S	959	26	58	449	218	74	302
L	05/16	S	960	28	61	482	225	86	305
L	06/21	C	848	38	88	459	197	86	331
L	06/21	C	847	34	85	432	184	79	313
L	06/21	C	846	35	74	424	175	73	299
L	06/21	C	845	38	87	454	186	83	316
L	06/21	C	844	38	85	455	190	85	318
L	06/21	C	830	39	89	446	187	81	324
M	05/20	S	1068	23	78	466	210	73	323
M	05/20	S	1069	20	87	457	212	77	309
M	05/20	S	1070	21	87	440	200	70	297
M	05/20	S	1071	21	91	465	209	75	312
M	05/23	S	961	23	96	448	221	79	324
M	05/23	S	962	40	35	480	231	63	316
M	05/23	S	963	20	36	458	224	62	325
M	05/24	S	965	24	86	513	225	72	312
M	05/24	S	966	23	96	494	240	81	331
M	05/24	S	967	23	108	520	245	84	335
M	05/24	S	964	24	114	522	245	82	354

TABLE C1 RESULTS OF SLUDGE AND BATCH COMPOST METALS ANALYSES (cont'd)

BATCH	DATE COLLECTED	TYPE (1)	SAMPLE #	METALS CONCENTRATIONS (mg/kg dry wt.)					
				Cd	Cr	Cu	Ni	Pb	Zn
M	06/29	C	874	34	96	468	194	75	331
M	06/29	C	873	32	90	434	193	80	310
M	06/29	C	872	35	95	431	199	81	324
M	06/29	C	832	36	92	452	206	79	326
M	06/29	C	883	36	101	446	206	81	334
M	06/29	C	885	36	96	431	210	83	337

(1) S sludge

C compost

NOTE: All of the dates collected are in the year 1988.

THE UNIVERSITY OF CHICAGO

DEPARTMENT OF THE HISTORY OF ARTS

1500 S. MICHIGAN AVE. CHICAGO, ILL. 60607

TEL: 773-936-3700 FAX: 773-936-3701

TABLE C2 AVERAGE METALS CONCENTRATIONS IN SLUDGE AND BATCH
COMPOST SAMPLES

BIN	SAMPLE TYPE (1)	METALS CONCENTRATIONS (mg/kg dry wt.)					
		Cd	Cr	Cu	Ni	Pb	Zn
A	S	43	90	459	196	60	265
	C	47	96	442	166	73	301
B	S	43	91	488	235	62	273
	C	47	97	433	189	76	318
C	S	33	74	529	216	59	298
	C	49	110	474	200	85	342
D	S	27	74	533	249	65	273
	C	SAMPLES LOST					
E	S	28	79	528	269	66	306
	C	SAMPLES LOST					
F	S	24	76	498	265	62	287
	C	40	103	434	233	70	325
G	S	17	69	478	227	53	262
	C	32	92	451	236	67	325
H	S	15	70	511	192	62	253
	C	28	76	456	176	68	310
I	S	15	73	517	177	57	270
	C	30	82	474	178	69	317
J	S	16	80	491	179	57	280
	C	33	90	481	175	74	330
K	S	22	83	504	194	109	337
	C	36	94	473	185	100	354
L	S	31	61	480	209	85	316
	C	37	85	445	187	81	317
M	S	24	83	478	224	74	322
	C	35	95	444	201	80	327

(1) S sludge
C compost

TABLE C3 RESULTS OF METALS ANALYSES OF STORED COMPOST SAMPLES

DATE COLLECTED	SAMPLE TYPE (1)	METALS CONCENTRATIONS (mg/kg dry wt.)					
		Cd	Cr	Cu	Ni	Pb	Zn
01/21/88	CP	83	123	427	191	93	360
02/10	CP	95	165	508	196	98	371
03/01	CP	92	149	505	198	101	361
	CP	102	152	540	207	109	375
03/17	CP	85	145	495	200	98	386
	CP	95	186	472	185	105	390
	SP	61	131	451	199	90	369
	SP	43	101	422	183	74	288
	SP	62	126	465	200	91	391
04/12	CP	101	146	485	204	98	368
	CP	95	153	445	181	96	365
	CP	99	169	471	194	100	367
	SP	55	112	494	243	90	360
	SP	48	98	430	195	75	309
	SP	53	109	460	217	85	341
05/03	CP	100	140	459	185	102	363
	CP	105	139	495	197	97	385
	CP	102	142	492	195	99	376
	SP	40	96	469	311	70	364
	SP	37	95	462	315	68	377
	SP	31	100	280	167	48	211
05/23	CP	94	124	450	173	94	381
	CP	84	116	418	170	86	365
	CP	93	136	450	174	96	378
	SP	36	92	428	187	68	333
	SP	37	87	447	192	71	335
	SP	37	90	432	184	70	326
06/21	CP	69	130	440	184	94	493
	CP	49	99	380	161	72	318
	CP	40	90	337	143	66	332
	SP	48	97	419	181	78	321
	SP	66	118	428	181	86	342
	SP	41	106	360	159	67	285

(1) CP curing pile
SP stockpiled

TABLE C4 AVERAGE METALS CONCENTRATIONS IN STORED COMPOST SAMPLES

DATE COLLECTED	SAMPLE TYPE (1)	METALS CONCENTRATIONS (mg/kg dry wt.)					
		Cd	Cr	Cu	Ni	Pb	Zn
01/21/88	CP	83	123	427	191	93	360
02/10	CP	95	165	508	196	98	371
03/01	CP	97	151	523	203	105	368
03/17	CP	90	166	484	193	102	388
	SP	55	119	446	194	85	349
04/12	CP	98	156	467	193	98	367
	SP	52	106	461	218	83	337
05/03	CP	102	140	482	192	99	375
	SP	36	97	404	264	62	317
05/23	CP	90	125	439	172	92	375
	SP	37	90	436	188	70	331
06/21	CP	53	106	386	163	77	381
	SP	52	107	402	174	77	416

(1) CP curing pile
SP stockpiled

APPENDIX D

COEFFICIENTS OF VARIATION OF METALS ANALYSES DATA

TABLE D1 COEFFICIENTS OF VARIATION OF METALS CONCENTRATIONS IN
SAMPLES (STUDY PERIOD)

SAMPLE TYPE	COEFFICIENT OF VARIATION (Percent)					
	Cd	Cr	Cu	Ni	Pb	Zn
Sludge	38.16	15.67	6.87	16.24	23.86	12.91
Batch Compost	21.30	12.36	6.35	13.19	14.16	6.77
Stockpiled Compost	23.47	12.57	11.98	22.71	15.42	13.62
Cured Compost	20.59	16.94	10.60	36.58	11.20	9.26

TABLE D2 COEFFICIENTS OF VARIATION OF METALS CONCENTRATIONS IN
SLUDGE SAMPLES (DAILY)

DATE	NUMBER OF SAMPLES	COEFFICIENT OF VARIATION (Percent)					
		Cd	Cr	Cu	Ni	Pb	Zn
01/21/88	9	4.64	3.05	2.83	4.08	9.28	5.27
01/22	4	1.99	1.19	2.65	1.35	12.20	2.96
01/25	4	2.72	3.06	3.38	3.22	5.07	2.43
01/27	4	2.15	3.36	3.24	1.94	9.13	2.14
01/28	3	2.27	5.43	2.59	2.42	5.26	3.78
01/29	3	1.39	2.73	1.53	1.25	19.58	12.32
02/01	4	2.04	9.75	3.51	3.61	12.46	4.63
02/09	4	2.55	5.86	3.95	1.56	8.57	48.02
02/10	4	0.00	4.49	4.08	4.36	6.92	6.49
02/11	4	2.88	5.31	2.75	1.36	3.72	4.14
02/19	3	2.11	2.02	1.24	2.97	6.81	3.13
02/23	4	7.50	3.87	1.12	1.60	3.51	1.90
02/24	4	3.39	3.44	1.91	1.72	3.69	2.03
03/01	3	5.59	3.32	2.18	1.07	8.01	3.20
03/02	3	2.09	0.00	1.72	0.57	8.28	0.68
03/03	4	33.04	4.87	3.40	3.50	6.61	4.34
03/04	3	4.38	2.04	1.01	1.84	4.42	3.12
03/07	4	4.12	3.31	2.27	1.33	5.82	2.48
03/08	4	4.03	7.12	0.26	4.89	9.00	12.34
03/09	3	2.55	0.73	2.70	1.85	3.34	2.70
03/10	4	27.01	2.96	2.11	1.51	4.72	2.84
03/18	3	3.46	12.04	3.04	3.85	4.69	8.15
03/21	3	3.27	5.64	4.76	2.36	4.90	2.51
03/22	3	3.33	3.19	5.03	5.05	4.90	4.05
03/23	3	3.53	7.02	2.65	2.92	7.98	3.73
03/24	3	0.00	3.09	0.43	0.93	8.81	5.13
03/25	3	3.33	1.43	3.88	3.57	1.06	5.91
03/31	3	14.52	1.54	2.20	0.59	8.25	1.74
04/01	4	6.45	3.39	1.20	0.77	21.23	4.00
04/04	4	3.77	0.67	1.50	1.41	5.44	1.90
04/11	3	0.00	2.47	2.30	1.67	21.81	2.80
04/12	4	0.00	5.91	3.70	1.78	8.66	7.75
04/13	4	3.28	6.95	2.79	5.19	7.32	5.79
04/19	4	3.08	5.10	1.49	7.20	8.56	3.78
04/20	2	4.88	0.00	1.75	2.11	17.83	6.17
04/21	2	4.88	4.45	4.47	3.78	1.37	6.29
04/22	3	9.17	3.27	6.44	7.99	7.81	11.01
04/25	4	6.42	4.59	3.76	12.87	24.03	9.29
05/03	4	7.38	14.47	2.24	3.33	5.22	3.39
05/04	4	10.95	5.17	3.04	1.25	7.79	4.82
05/05	4	6.70	4.62	8.23	2.17	1.72	3.27
05/11	4	28.06	8.81	3.88	5.10	2.77	2.23
05/12	3	16.87	28.33	0.24	0.75	11.07	2.05

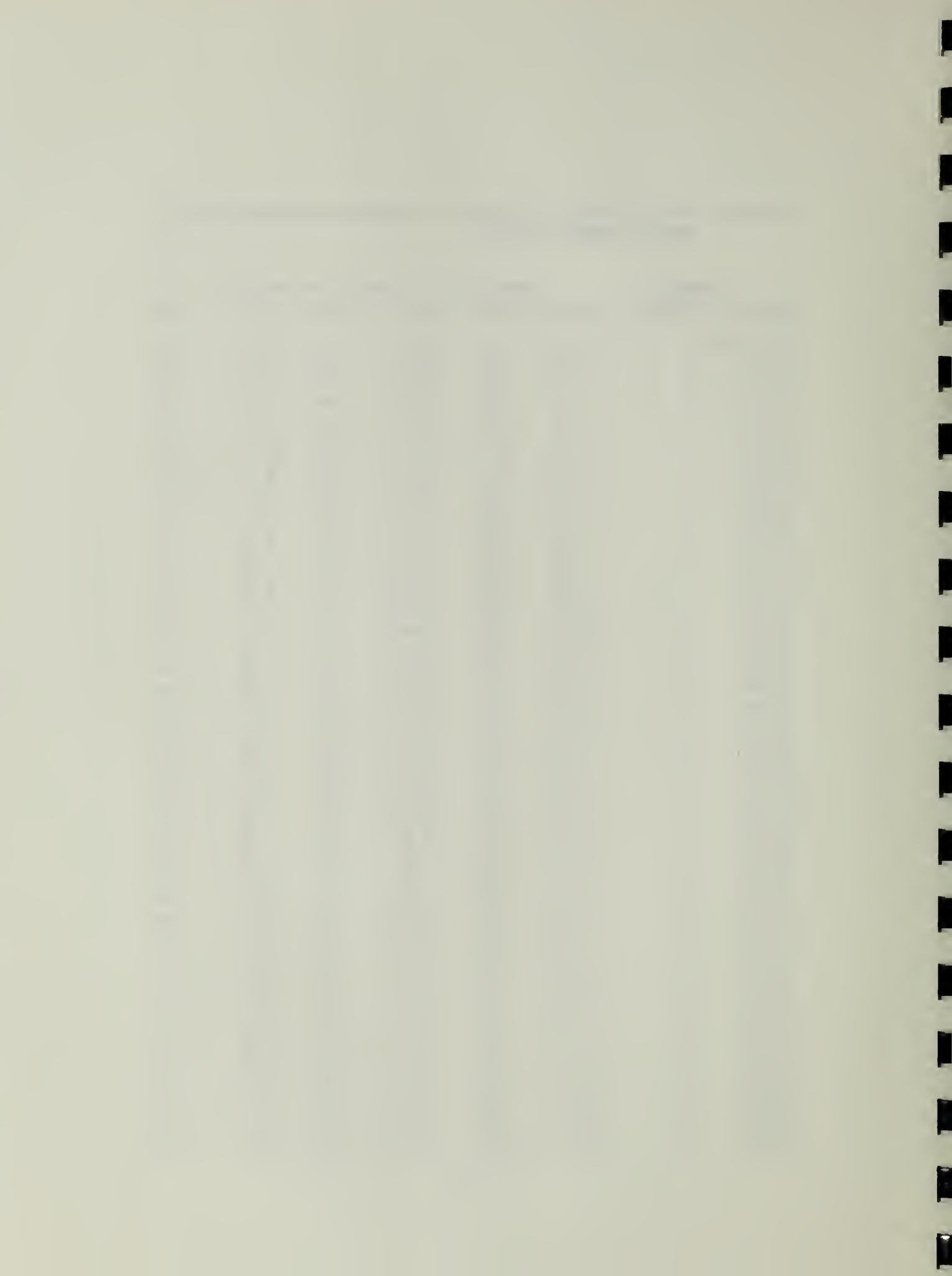


TABLE D2 COEFFICIENTS OF VARIATION OF METALS CONCENTRATIONS IN
SLUDGE SAMPLES (DAILY) (continued)

DATE	NUMBER OF SAMPLES	COEFFICIENT OF VARIATION (Percent)					
		Cd	Cr	Cu	Ni	Pb	Zn
05/13	3	33.68	39.40	4.93	3.06	11.92	4.08
05/16	4	9.87	4.60	3.53	2.28	7.30	1.56
05/20	4	5.92	6.41	2.63	2.56	4.05	3.45
05/23	3	38.98	62.75	3.54	2.28	14.03	1.53
05/24	4	2.46	12.37	2.49	3.96	6.66	5.17
median		4.03	3.87	2.63	2.36	7.30	3.73

TABLE D3 COEFFICIENTS OF VARIATION OF METALS CONCENTRATIONS IN
STORED COMPOST SAMPLES (DAILY)

DATE	SAMPLE TYPE (1)	NUMBER OF SAMPLES	COEFFICIENT OF VARIATION (Percent)					
			Cd	Cr	Cu	Ni	Pb	Zn
03/01/88	CP	2	7.29	1.41	4.74	3.14	5.39	2.69
03/17	CP	2	7.86	17.52	3.36	5.51	4.88	0.73
	SP	3	19.32	13.74	4.92	4.92	11.22	15.53
04/12	CP	3	3.11	7.56	4.35	5.98	2.04	0.42
	SP	3	6.93	6.93	6.94	11.01	9.17	7.66
05/03	CP	3	2.46	1.09	4.14	3.34	2.53	2.95
	SP	3	12.73	2.73	26.55	31.90	19.62	29.09
05/23	CP	3	6.10	8.03	4.21	1.21	5.75	2.27
	SP	3	1.57	2.81	2.30	2.15	2.19	1.43
06/21	CP	3	28.18	19.73	13.41	12.63	19.06	25.52
	SP	3	24.96	9.85	9.18	7.31	12.39	9.12

(1) CP Curing pile
SP Stockpiled

TABLE D4 COEFFICIENTS OF VARIATION OF METALS CONCENTRATIONS IN
SLUDGE AND BATCH COMPOST SAMPLES (BATCH)

BATCH	SAMPLE TYPE (1)	Cd	Cr	Cu	Ni	Pb	Zn
A	S	6.83	12.66	7.94	22.30	9.11	4.17
	C	6.30	5.65	3.85	4.36	9.11	5.91
B	S	6.47	5.84	3.74	7.11	17.32	6.74
	C	12.37	10.47	6.71	4.86	12.32	7.95
C	S	2.63	6.87	6.32	2.85	6.83	32.51
	C	14.29	9.79	6.16	5.80	9.57	4.94
D	S	6.42	3.67	2.08	9.71	4.55	2.54
	C	--	--	--	--	--	--
E	S	20.33	5.56	2.49	1.97	6.42	3.45
	C	--	--	--	--	--	--
F	S	13.15	4.92	1.92	4.36	5.71	6.19
	C	16.78	12.96	11.98	6.44	10.16	7.69
G	S	4.48	6.38	3.72	4.79	5.67	5.00
	C	3.71	2.25	3.40	11.59	4.77	5.26
H	S	14.26	5.84	2.24	2.25	12.99	4.05
	C	8.37	5.69	5.08	2.78	9.44	6.77
I	S	2.03	6.70	4.18	4.08	15.64	6.86
	C	5.73	2.23	2.14	1.77	4.16	5.27
J	S	9.90	3.71	3.78	8.74	15.53	7.68
	C	6.81	8.09	2.14	4.94	3.49	3.61
K	S	22.93	10.48	5.45	5.66	10.65	4.63
	C	4.08	6.08	1.92	2.72	6.16	4.10
L	S	25.27	26.52	6.03	5.10	12.32	4.43
	C	5.42	6.43	3.16	3.87	5.87	3.42
M	S	23.20	30.87	6.16	6.83	9.86	4.73
	C	4.57	3.99	3.31	3.50	3.40	2.94
median	S	9.90	6.38	4.18	5.10	9.86	4.73
	C	6.30	6.08	3.40	4.36	6.16	5.26

(1) S sludge
C batch compost

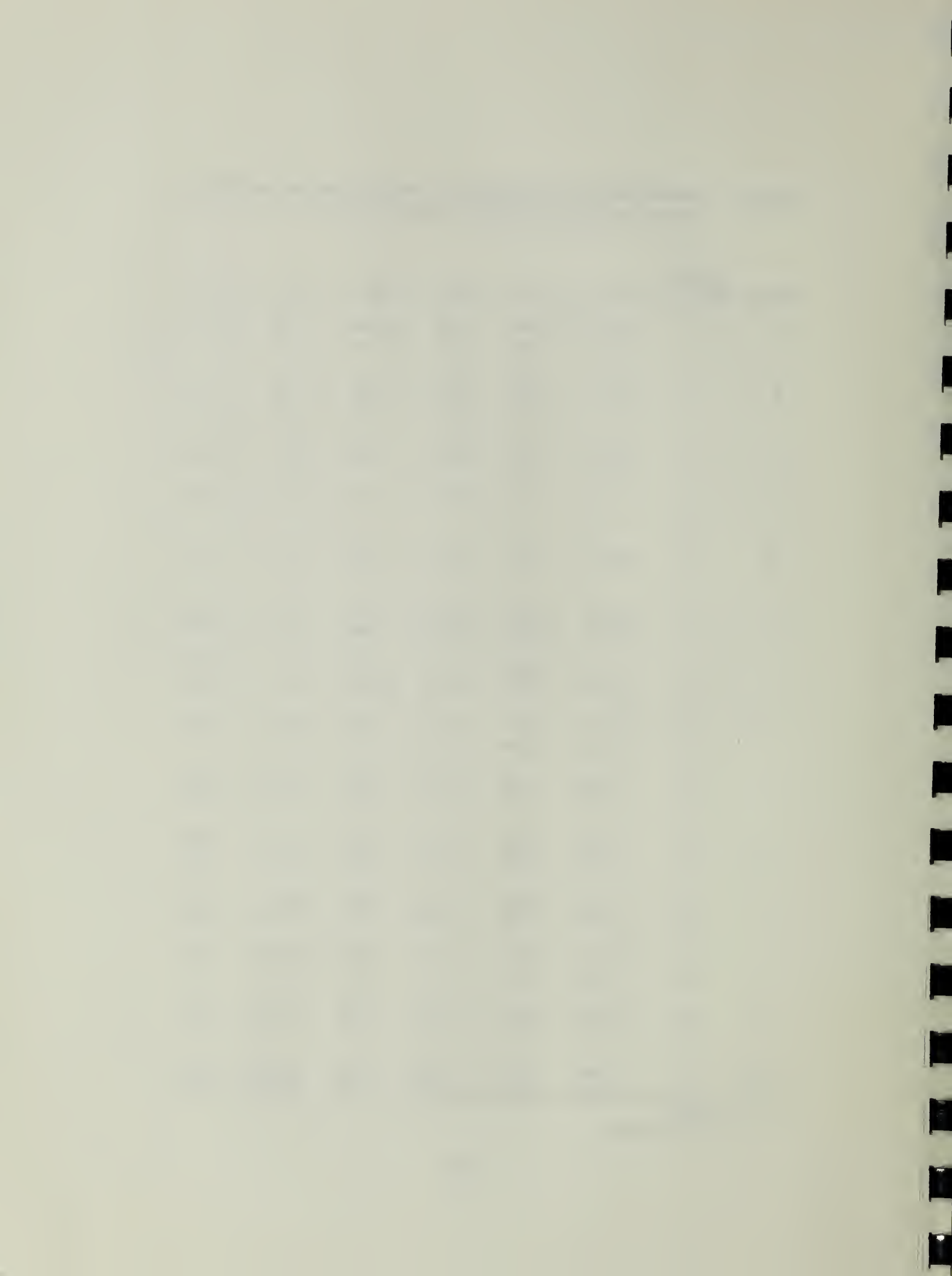


TABLE D5 COEFFICIENTS OF VARIATION OF AVERAGE METALS
CONCENTRATIONS (ALL BATCHES)

SAMPLE TYPE	COEFFICIENT OF VARIATION (Percent)					
	Cd	Cr	Cu	Ni	Pb	Zn
SLUDGE	36.89	10.93	4.60	14.02	22.50	8.99
BATCH COMPOST	19.24	10.24	4.02	11.85	12.63	4.50

TABLE D6 COEFFICIENTS OF VARIATION OF PERCENT CHANGE IN SLUDGE
METALS CONCENTRATIONS DURING COMPOSTING

METAL	COEFFICIENT OF VARIATION (Percent)
Cd	60
Cr	72
Cu	43
Ni	89
Pb	91
Zn	59

